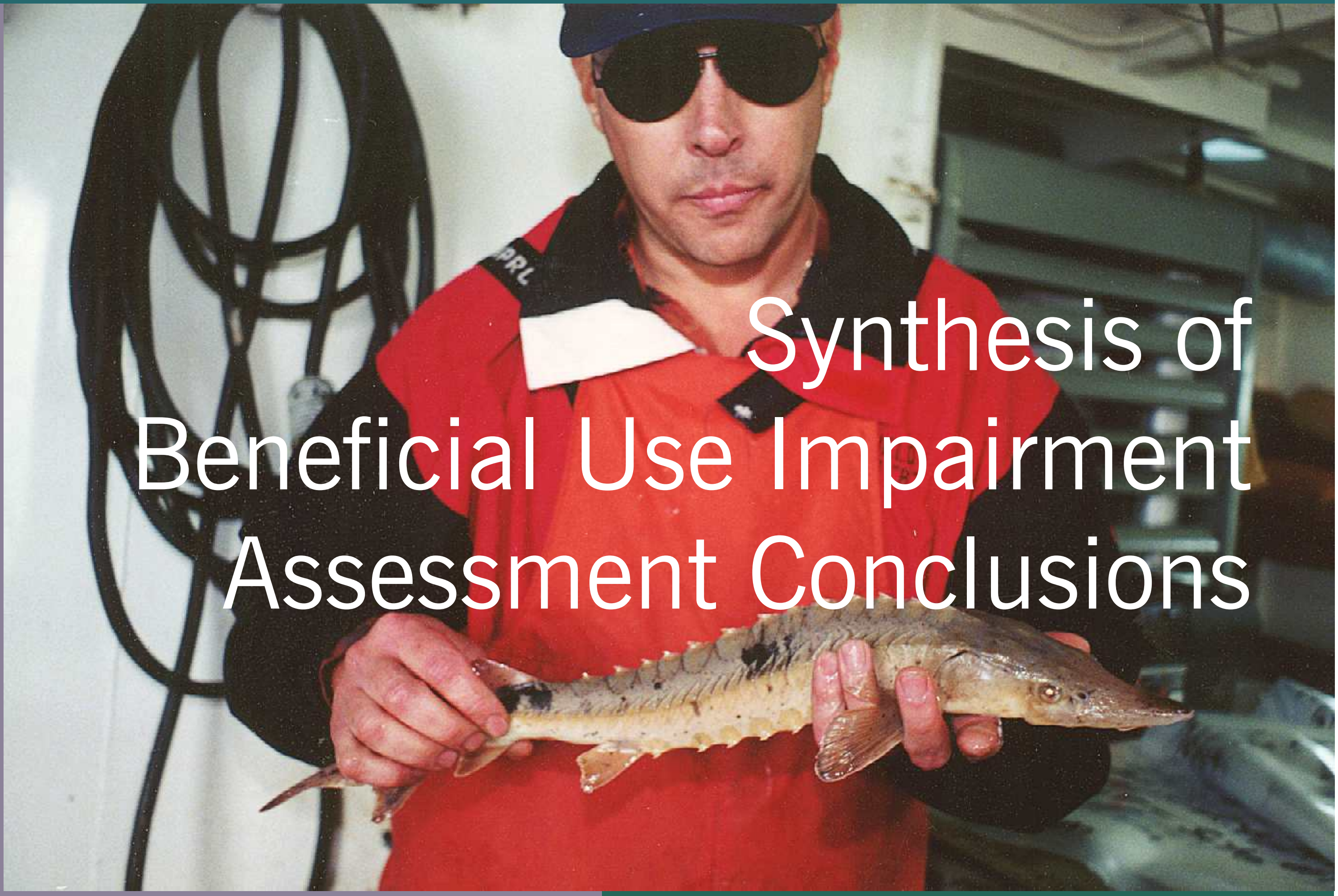


Synthesis of Beneficial Use Impairment Assessment Conclusions

Photo: John Cooper

Section 4: Synthesis of Beneficial Use Impairment Assessment Conclusions

4.1 Introduction

Scope

Annex 2 of the Great Lakes Water Quality Agreement requires that each LaMP assess impairment to14 beneficial water resource uses as the first step in identifying restoration and protection actions for each of the Great Lakes. The 14 beneficial use impairments and the criteria for determining impairment are outlined in Table 2.1. The Lake Erie LaMP also recognizes that more than just these 14 beneficial use impairments will need to be addressed before Lake Erie can be fully restored. These other issues, or stressors, are discussed in other sections of the LaMP 2000 document.

The geographic scope of the impairment assessment includes the open waters of Lake Erie, nearshore areas, embayments, river mouths and the lake effect zones of all Lake Erie tributaries. The location of the cause or source of an impairment does not have to fall within the above-mentioned geographic boundaries to be considered within the LaMP evaluation process. **When an impaired beneficial use is identified in a particular basin in the summary tables throughout this section, it means that impairment is occurring somewhere in that basin, not necessarily throughout the entire basin referenced.**

The Ecosystem Approach in Action - Step 1

For the Lake Erie LaMP, the term ecosystem approach means: a) remediating both contaminant and noncontaminant causes of impairment is important to the restoration of Lake Erie, and b) management actions must consider impacts to all key components of the Lake Erie ecosystem before they are implemented.

In keeping with item “a”, this preliminary beneficial use impairment assessment treats all impairments and known causes equally, regardless of the type, severity, duration, trend, geographic extent, or magnitude. The primary causes of impairment are chemical contaminants, habitat loss and degradation, exotics and the associated impacts to energy and contaminant flow in the food web. Remediation of any one of these causes without addressing the others will not fully restore Lake Erie.

In terms of item “b”, existing objectives such as those in the North American Waterfowl Management Plan (NAWMP), the National Shorebird Plan, Partners in Flight and the Lake Erie Fish Community Goals and Objectives (FCGO) were used to complete the preliminary beneficial use impairment assessment. Some of these existing objectives were developed with primarily one group of organisms in mind, and not necessarily the entire ecological community. In the case of wildlife, most of the objectives are not Lake Erie specific. It is important to use and fine tune existing objectives with new proposed objectives to prevent conflicting management actions. An example of such a conflict is diked wetlands that protect wildlife habitat from destruction by lake wave action and serve as a refuge for native mussels, but do not provide optimal fish habitat.

The Lake Erie LaMP has developed a model, described in Section 3 of this document, which will allow us to explore the effects of changes in management strategies on all parts of the ecosystem. This model is being used by the LaMP to assist in developing ecosystem objectives specific to Lake Erie. When final ecosystem objectives are selected they will allow us to characterize the severity of a given impairment in relation to LaMP targets for restoration. This will provide the tool needed to prioritize actions that must be implemented to restore beneficial uses.

Synthesis Approach

It is recognized that many improvements already have occurred in the Lake Erie environment. However, because the intent of the LaMP 2000 Report is to set the stage for future actions in Lake Erie, the text in this section of the document addresses only problems that are still occurring. The impairment conclusions for each of the 15 Lake Erie assessments (fish and wildlife assessments were done separately) are summarized in tables within each subsection and serve as the preliminary problem definition for the lake. Eleven of the 15 assessments concluded that impairment is occurring somewhere within the geographic scope of the Lake Erie LaMP.

In general, more impairments are identified in the western basin and in the lake effect zones of tributaries than in the other two basins. However, this fact must be interpreted carefully. While it is known that contaminant impacts are generally greatest in the western basin, there are several other key considerations. The range of certain sensitive species is limited to the western basin and acreage of certain habitat types was historically greatest in the western basin. For example, in terms of impacts to coastal wetlands, the former Black Swamp alone covered nearly 300,000 acres before land use changes reduced the remaining acreage to the current 30,000 acres. In other cases most of the data is collected from the western basin. Nearly all of the benthos data in existence comes from the western basin. Because the states and province are responsible for regulating surface waters in their respective jurisdictions, an abundance of tributary data is available. Seven of the 12 Lake Erie basin AOCs are located in the western basin or watershed and have already completed extensive beneficial use impairment assessments for those specific geographic areas. And, finally, certain impairments are limited to tributaries and nearshore areas by default (e.g. beach impairments, wildlife consumption advisories, fish tumors or other deformities, and restrictions on dredging activities).

To date, each beneficial use has been examined only in relation to the impairment criteria for that particular use. Therefore, the purpose of this section is to briefly synthesize the 14 assessments by linking the impairment conclusions, causes, and trends among impairments for the first time. Impairment assessment conclusions have been grouped into three broad categories based on the primary areas of public interest to date: human use impairments (section 4.2), impairments due to chemical contaminants (section 4.3), and ecological impairments (section 4.4), with a synthesis narrative for each.

For many of the assessments, there are data gaps that hinder our understanding of impairment and/or its causes. These data gaps are summarized in each subsection below. More detailed technical information is available on-line at http://www.epa.gov/glnpo/lakeerie/buia/index.html for each assessment with an **asterisk (*). The remaining impairment conclusions are draft.**

4.2 Human Use Impairments

The human use assessment results answer the questions, are Lake Erie waters: a) fishable, b) swimmable, c) drinkable, d) navigable, and e) clean enough for routine agricultural and industrial use? The impairment conclusions for each are summarized in Table 4.1 and show that Lake Erie waters are not yet completely fishable, navigable, and swimmable. The major causes of these impairments to human use are chemical contaminants and elevated levels of bacteria in recreational waters.

Table 4.1 Summary of Human Use Impairments

Impaired Use	Impairment Conclusions by Basin	Causes of Impairment
Fish and Wildlife Consumption Restrictions*	*FISH* –**Impaired** in all basins (Table 4.2) *WILDLIFE* -**Impaired** in eastern basin; inconclusive for western and central basins	*FISH* - PCBs, mercury, lead, chlordane, and dioxins *WILDLIFE* - PCBs, chlordane, DDE, DDT and mirex
Tainting of Fish and Wildlife Flavor*	Not Impaired	None
Restrictions on Dredging Activities*	**Impaired** in tributary mouths and harbors of all basins (Table 4.3)	PCBs, heavy metals
Restrictions on Drinking Water Consumption or Taste and Odor Problems*	Not Impaired	None
Recreational Water Quality Impairments*	**Impaired** in nearshore waters of all basins; Inconclusive for offshore waters of all basins	Exceedances of *E. coli* and/or fecal coliform guidelines, PAHs+, PCBs+
Degradation of Aesthetics*	**Impaired** in nearshore waters, all basins; Inconclusive for open waters of the western basin (Table 4.4).	Excessive *Cladophora*, point/nonpoint source stormwater runoff, floating garbage and debris, dead fish, excessive zebra mussels on shoreline areas.
Added Costs to Agriculture and Industry*	Not Impaired	None

+ PAHs are the basis for a human contact advisory in the Black River Ohio Area of Concern and PCBs are the basis for a human contact advisory in the Ottawa River (Maumee Area of Concern). These advisories were issued by the Ohio Department of Health and mean that it is not safe to go into the water in these areas.

4.2.1 Fish Consumption Restrictions

Fish consumption impairments occur when contaminant levels in fish exceed current standards, objectives or guidelines, or public health advisories are in effect for human consumption of fish or wildlife. Impairment to human consumption of Lake Erie fish is occurring. Public health advisories for human consumption of sport fish are in place for many geographic locations within Lake Erie waters. Particularly noteworthy are "DO NOT EAT" consumption advisories for certain species/size classes of fish in Lake Erie, Maumee and Long Point Bays, the Maumee, Detroit, Raisin and Rouge River AOCs, and the Buffalo River/Harbor area. In addition, commercial fishermen in Ontario are prohibited from selling carp that are 32 cm or larger, due to PCBs.

Table 4.2 Summary of Sport Fish Consumption Advisories by Lake Erie Basin

Western Basin Nearshore	Impaired. Fish advisories for Maumee, Portage, Sandusky, Raisin, Rouge, Detroit, and Ottawa River tributaries, and Wheatley Harbor and Maumee Bay.
Western Basin Offshore	Impaired Fish advisories for Lake Erie waters of all jurisdictions bordering this basin.
Central Basin Nearshore	Impaired. Fish advisories for Vermilion, Huron, Black, Cuyahoga, Ashtabula, Chagrin River and Conneaut Creek tributaries and Rondeau Bay.
Central Basin Offshore	Impaired. Fish advisories for Lake Erie waters of all jurisdictions bordering this basin.
Eastern Basin Nearshore	Impaired. Fish advisories for Presque Isle Bay, Buffalo River/Harbor. Grand River, Ontario, Big Creek, and Long Point Bay.
Eastern Basin Offshore	Impaired. Fish advisories for Lake Erie waters of all jurisdictions bordering this basin.

The presence of contaminants in Lake Erie, which are the basis for these advisories, exceeds the Lake Erie Committee (LEC) draft objective related to fish consumption advisories. The goal of this objective is to "reduce contaminants in all fish species to levels that require **no advisory** for human consumption . . ." The existence of fish consumption advisories also does not meet the IJC objective of no restrictions on the human consumption of fish in waters of the Great Lakes Basin Ecosystem.

Fish consumption advisories are issued to assist sport fish consumers in protecting their health. The goal of advisories is to minimize human exposure to chemical contaminants that are present in fish tissue. The choice of which fish to consume, how frequently to consume, and how to prepare remains with the individual. In contrast, commercial fishing restrictions are enforceable standards and are therefore mandatory.

The most common chemical causes of sport fish consumption advisories are PCBs and mercury, although advisories in some areas are issued due to lead, chlordane and dioxins. Additional chemical parameters that are routinely monitored vary by jurisdiction. Sport fish consumption advisories are educational tools that not only identify geographic locations where fish are affected, but also inform consumers of fish species and size classes likely to contain higher levels of chemical contaminants, offer recommendations on frequency of consumption, and recommend preparation and cooking techniques that reduce risk of exposure to contaminants that accumulate in fatty tissues, such as PCBs. The presence of mercury in fish has been of particular concern because it accumulates in the tissue of fish rather than the fat. Food preparation methods such as trimming fat and skin, and broiling rather than frying do not reduce exposure to mercury. The only effective option to minimize exposure to mercury present in fish tissue is to follow fish consumption advisories and to avoid eating the internal organs of the fish.

As an example of jurisdictional efforts to address the mercury concern, Ohio has issued a general precautionary consumption advisory for women of childbearing age and children age 6 and under, for all species of fish in all Ohio waters. This is due to the presence of mercury at low background levels in nearly all Ohio fish samples tested. Due to frequency of consumption or traditional ethnic means of food preparation, subsistence anglers and certain cultural and immigrant groups may also be at greater risk of adverse effects due to contaminant exposure. More restrictive consumption frequency advisories are issued for these groups, such as the statewide Ohio mercury advisory and the Ontario mercury advisory for subsistence fishermen.

Carp is the fish species most frequently identified in consumption advisories, although numerous other species are identified in various locations, particularly channel catfish and freshwater drum. The different species restrictions apply to particular sizes of fish, based on the results of fish tissue sampling and varying rates of bioaccumulation.

4.2.1.1Ongoing Research and Data Gaps

Fish consumption restrictions may need to be updated in the future as conditions change. For example, reductions in contaminant levels in the food chain may allow some advisories to be lifted. Since 1970, levels of mercury in Lake Erie basin walleye have dropped substantially. However, between 1992 and 1995 levels have varied and may be increasing, at least in Lake St. Clair walleye (Straughan et al. 1999). In 1995, Ontario Ministry of the Environment issued more conservative consumption advisories in the Detroit River for the largest size class of walleye, recommending a drop in consumption from four meals/month to two meals/month. Currently, mercury and PCBs are the only contaminants limiting fish consumption in the Detroit River. Ontario data for mercury levels are not yet conclusive (Straughan et al. 1999), but are consistent with U.S. EPA data (U.S. EPA 1999) presented at a meeting held in response to public and scientific concerns about increased mercury in walleye. However, data from Michigan's whole fish contaminant monitoring program (1990 to present) do not indicate an increasing mercury trend for the Detroit River (Bob Sweet, pers. comm.).

Changes in bioavailability of contaminants may eventually affect fish consumption advisories. Zebra mussel research suggests that PCBs are being more quickly biomagnified up the food chain through a zebra mussel-round goby-small mouth bass connection (Ohio Sea Grant, 1999).

Research is underway to quantify the levels of microcystin present in fish tissue collected in areas where *Microcystis* blooms have occurred. Microcystin is a potent liver toxin produced by the blue-green algae *Microcystis*. In addition to evaluating the effect of microcystin levels on fish health, the results of the current research will identify whether microcystin is present in fish tissue at levels that impact the health of human consumers (Culver, 1999).

4.2.2 Wildlife Consumption Restrictions

Wildlife contaminant research has been extensive in the Great Lakes, but generally as it pertains to wildlife, not human health. Of the Lake Erie jurisdictions, only New York has established criteria for implementing wildlife consumption restrictions, although Ontario and Michigan have done research to evaluate potential need for consumption advisories for waterfowl, and Ohio has research underway for snapping turtles. Public health advisories for human consumption of snapping turtles and waterfowl are in place for New York waters of Lake Erie. The contaminants causing these advisories are PCBs, mirex, chlordane, and DDTs.

4.2.3 Restrictions on Dredging Activity

Between 1984 and 1995, 25 navigational areas around Lake Erie were dredged. Twelve of the 25 areas dredged have required the dredged material to be disposed in a confined disposal facility (CDF) at some time during this period. Seven of these sites (Ashtabula, Cleveland, Lorain, and Toledo, Ohio, and Detroit, Rouge River and Monroe, Michigan) currently require confined disposal for most of the sediment dredged from those areas. Because there are restrictions on disposal of dredged materials, this use is considered impaired. Water quality standards and criteria for disposal of sediments vary among jurisdictions, but throughout the basin PCBs and heavy metals are the most commonly identified contaminants that dictate confined disposal. A PAH-contaminated site was remediated by dredging and remedial dredging is planned in at least three other sites around the basin.

Table 4.3 Summary of Lake Erie Navigational Dredging Activity 1984-1995, by jurisdiction

Jurisdiction	Michigan	New York	Ohio	Ontario	Pennsylvania
# of Locations	4 locations 3 AOCs	1 location 0 AOCs	12 locations 4 AOCs	7 locations 1 AOC	1 location 1 AOC
Volume (cu. yd.)	3,585,200	101,400	20,928,600	788,135	177,800
Cost (U.S.$)	$25,642,900	$382,800	$71,007,700	$4,801,400	$502,300

4.2.3.1Ongoing Issues and Research

The trend of disposing of dredged materials into confined disposal facilities is changing. As concentrations of contaminants in sediment continue to fall and CDFs reach their maximum capacity, there is a greater likelihood that other alternatives such as open-lake disposal, beach nourishment, upland disposal, or other beneficial reuse will occur. Both Canada and the U.S. have funded programs to investigate and demonstrate the use of remedial technologies to treat contaminated sediments and reduce the amounts that need to be placed in disposal facilities.

Although the major point sources of pollutants to sediments have decreased, methods and criteria for assessing the effects of contaminated sediments have become more stringent and could conversely contribute to a greater amount of contaminated sediments to handle. In addition, falling lake levels are necessitating more dredging to maintain navigation than in the previous three decades.

4.2.4 Recreational Water Quality Impairments

Annex 1 of the Great Lakes Water Quality Agreement (GLWQA) states that: "*Waters used for body contact recreation activities should be substantially free from bacteria, fungi, or viruses that may produce enteric disorders or eye, ear, nose, throat and skin infections or other human diseases and infections*" (IJC, 1989). Annex 2 of the GLWQA lists "beach closings" as a beneficial use impairment related to recreational waters. According to the International Joint Commission (IJC), a beach closing impairment occurs "*when waters, which are commonly used for total body contact or partial body contact recreation, exceed standards, objectives, or guidelines for such use*" (IJC, 1989).

Therefore, the major human health concern for recreational use of Lake Erie waters is microbiological contamination (bacteria, fungi, viruses, and parasites). Human exposure occurs primarily through ingestion of polluted water, and can also occur through the entry of water into the ears, eyes, nose, broken skin, and through contact with the skin.

Gastrointestinal disorders and minor skin, eye, ear, nose and throat infections have been associated with microbiological contamination.

As noted above, recreational water quality impairment includes situations where partial body contact recreation standards are exceeded. To be complete, an assessment needs to evaluate all recreational water use activities where total or partial body water contact may occur. This includes primary activities such as swimming, windsurfing and water skiing, and also situations where swimming may occur in open waters during secondary contact activities, such as boating and fishing. The assessment considers both nearshore and open water activities in its evaluation of impairment, thus, the change in title from *beach closings* to *recreational water quality impairments*.

Federal, state and provincial recreational water quality guidelines recommend bacterial levels below which the risk of human illness is considered to be minimal. When contaminant indicator levels in the bathing beach water reach levels that indicate contaminants may pose a risk to health, public beaches are posted with a sign warning bathers of the potential health risk. The primary tool to evaluate beach water quality is the measurement of *indicator organisms*, which indicate the level of bacterial contamination of the water. The two indicator organisms most commonly used to measure bacterial levels are *fecal coliform* and *Escherichia coli* (*E.coli)*. High levels of fecal coliform or *E. coli* in recreational water are indicative of fecal contamination and the possible presence of intestinal-disease-causing organisms. However, it should be noted that neither *E. coli* nor fecal coliform testing differentiates between human or animal waste, or indicates the presence of viruses or of non-fecal contaminants (e.g. *Staphylococcus*).

4.2.4.1Impairment Conclusions

Bacterial level exceedances are occurring at beaches throughout the Lake Erie basin. Therefore, Lake Erie basin nearshore recreational water quality is impaired from a human health (i.e. bathing use) standpoint. Bacterial levels data examined in this assessment provide support for a conclusion that recreational use of Lake Erie offshore is unlikely to be impaired by bacteria. However, based on a request from the Binational Public Forum, the Lake Erie LaMP has decided to classify the use impairment for recreationally used "open waters" as "inconclusive", since a recent comprehensive data-set for open lake waters is not available for assessment.

Many sources contribute to microbiological contamination, including combined or sanitary sewer overflows, unsewered residential and commercial areas, and failing private, household and commercial septic systems. However, it is important to note that simply because bacterial levels are present, it does not necessarily mean that sewage overflow is a problem. Other sources may be agricultural runoff (e.g. manure); fecal coliforms from animal/pet fecal waste washed from soil by heavy rains, either from the beach or washed into residential storm sewers; wildlife waste, as from large populations of gulls or geese fouling the beach; direct human contact, e.g. swimmers with illnesses, cuts or sores; or high numbers of swimmers/bathers in the water, which are related to increased bacterial levels; and direct discharges, for example from holding tanks of recreational vessels. Other factors affecting contamination levels are low (shallow) water levels; hot weather/higher temperatures; high winds that can cause increased wave action that can transport bacteria from contaminated, non-recreational areas to recreational-use areas; high winds that can stir up bacteria that are in the sediments; and calmer waters that can slow dispersal and create excess concentrations of bacteria.

4.2.5 Degradation of Aesthetics

An aesthetic impairment occurs when any **substance in water** produces a **persistent** objectionable deposit, unnatural color or turbidity, or unnatural odor (e.g. oil slick, surface scum) (emphasis added, IJC, 1989).

For the Lake Erie LaMP process, the IJC listing criteria for evaluating aesthetic impairments in Lake Erie have been adopted with the following additions:

- Whether an aesthetic problem is *naturally* occurring or *man-made* does not affect its potential designation as an impairment;
- The fact that there is currently no known solution to an aesthetic problem does not affect its potential designation as an impairment.

With the exception of beneficial use impairment assessments already completed for Lake Erie AOCs, Lake Erie aesthetic problems have not previously been evaluated collectively. In most cases the locations, frequency, duration, and magnitude of any identified aesthetic problems or impairments have not been regularly tracked through any formal monitoring program. In addition, there is no precise/common definition for a "persistent objectionable deposit." Therefore, detailed information is largely anecdotal and inherently subjective.

The purpose of this assessment is to: a) outline all known instances of aesthetics problems in Lake Erie waters, b) evaluate the nature of these problems, where possible, and c) to distinguish between aesthetic impairments to use of Lake Erie, as defined by the IJC listing criteria, and other aesthetic issues of concern that do not meet the listing criteria. To date, the Lake Erie LaMP process has identified the following list of potential aesthetic problems: high turbidity, obnoxious odor, excessive *Cladophora*, excessive blue-green algae, nuisance conditions at public beaches/ lake shoreline, excessive aquatic plants washing up onto beaches and shorelines, floating garbage/debris, and dead fish.

4.2.4.1Impairment Conclusions

Table 4.4 Summary of Lake Erie Aesthetic Impairment Conclusions

Type of Impairment	Determination of Impairment	Location/Extent of Impairment	Known Causes of Impairment	Notes
High Turbidity	**Impaired.**	Maumee, Rouge River and River Raisin AOCs - western basin; Black and Cuyahoga (navigation channel) AOCs - central basin.	Agricultural and urban point and nonpoint source runoff and storms stirring up bottom sediments.	
Obnoxious Odors	**Impaired** due to dead fish and *Cladophora*; Inconclusive due to decaying zebra mussels.	Cuyahoga AOC - central basin (fish); *Cladophora* fouling has occurred at Lake Erie State Park Beach, New York and Rondeau Bay, Ontario.	Decaying algae and fish.	Although decaying zebra mussels and combined sewer overflow discharges of raw sewage are known to cause obnoxious odors, it appears from information to date that these problems are not persistent in Lake Erie.
Excessive *Cladophora*	**Impaired.**	Eastern and central basin nearshore - nearshore and river mouths in Ontario waters (eastern basin) and Rondeau Bay, Ontario (central basin).	Nutrient enrichment, availability of substrate.	
Blue-green Algae	Inconclusive.	Western basin.	Emerging issue. Research is underway to pinpoint cause of Microcytstis bloom. Hypothesis that zebra mussels may be contributing to the problem.	It is not known whether extensive Microcystis blooms will continue to persist. Therefore a definitive impairment determination has not been made.
Aquatic Plant Deposits at Public Beaches	Not Impaired/No documentation to date showing a persistent problem.	N/A	N/A	
Zebra Mussel Shells at Public Beaches	Inconclusive.	Large deposits of shells have been reported at many western basin beaches and at Presque Isle Bay State Park, central basin.	Deposits of zebra mussels/ shells.	It is not known whether reported problems are persistent and, if so, if they are interfering with human use of shoreline areas.

Type of Impairment	Determination of Impairment	Location/Extent of Impairment	Known Causes of Impairment	Notes
Floating Garbage and Debris	**Impaired.**	Geographic extent of impairment is localized, Cuyahoga AOC, Headlands Dune State Nature Preserve - central basin.	Large quantities of floating debris (primarily natural), Cuyahoga AOC; interfering with navigational, recreational, and industrial use of affected area in Cuyahoga AOC. Large quantities of floating garbage (primarily combined sewer overflow-related) have led to citizen complaints at Headlands Dunes State Nature Preserve.	This issue is significant enough for the Cuyahoga AOC, that a proposal to purchase a debris harvester is being pursued.
Dead Fish	**Impaired.**	Geographic extent of impairment is seasonal and localized. Cuyahoga AOC - central basin, Ontario eastern basin waters are only documented impairments to date.	Seasonal die-offs due to alewife/other exotics not acclimated to colder water temperatures.	

N/A = Not Applicable

4.2.5.2 Emerging Issues

There are two current Lake Erie phenomena that have aesthetic ramifications, but are also indicators of much broader ecosystem changes in Lake Erie - *Microcystis* blooms and the reappearance of the burrowing mayfly, *Hexagenia limbata*. Research is currently underway to determine the cause and potential implications of the recent *Microcystis* blooms in the western basin. The LaMP will use the research findings, when available, to reevaluate the status of *Microcystis* blooms as an aesthetic impairment to the western basin of Lake Erie. The emerging issue of mayfly reappearance exemplifies the conflict between traditional indicators of improving ecosystem quality and perceived aesthetic problems. During the final stage of their life cycle, burrowing mayflies emerge from Lake Erie sediments and swarm in such large numbers they have made roads slippery and caused temporary brown-outs. These swarms of mayflies are regarded as a signal of improving Lake Erie water quality, but create a temporary nuisance to humans. Because the mayfly is widely regarded as a signal of improving water quality, any aesthetic problems created by swarming have not been classified as an impairment in this assessment. However, it is acknowledged that there can be temporary conflicts between the improving Lake Erie ecosystem and certain desired human uses of the Lake region during the mayfly swarming period.

4.3 Impairments Caused by Chemical Contaminants

Overview

Both contaminant loadings to the lake and contaminant levels in biota have decreased from levels recorded in the 1960s and 1970s. However, Lake Erie still contains a legacy from the past in the form of contaminated sediments that were deposited before bans on the use of certain chemicals and pollution reduction initiatives were implemented. Contaminants are clearly bioaccumulating in Lake Erie biota on a continuum from benthos to fish to amphibians, reptiles, birds and mammals, resulting in the specific impairments summarized in Tables 4.5 through 4.7. In addition, the filter feeding habits of the non-indigenous invasive zebra mussel are re-introducing contaminants not previously biologically available back into the water column and ultimately into the food web.

The information in this section is organized by trophic level (benthos, fish, birds, and mammals) to more clearly illustrate the biomagnification concept. Benthic organisms spend most or all of their lifecycle in the sediment of the lake. Some fish are benthic feeders or spend most of the time near the bottom; others eat organisms that have spent part of their lifecycle as benthos. Finally, birds and mammals prey on the fish. Each organism has bioaccumulated contaminants during its lifecycle, and the effect magnifies as one moves up the food chain. There are species used as indicators of this phenomenon (midges, mayflies, brown bullhead, bald eagle and herring gull) for which we have the most information. However, the list of species used to monitor contaminant impacts has grown in recognition of widespread bioaccumulation.

It should be noted that contaminant studies tend to look at **effects to a particular organism in a particular location** versus population-wide effects. But when evidence from the ecological impairments (section 4.4) is combined with toxicological results, it can be seen that contaminants are often an important limiting factor to population health.

Summary Conclusions

Lake Erie basin impairments caused by chemical contaminants include restrictions to fish and wildlife consumption, restrictions on dredging activity, fish tumors or other deformities (section 4.3.2), bird and animal deformities or reproduction problems (section 4.3.3), and benthic deformities (section 4.3.1). Impairment conclusions for restrictions to fish and wildlife consumption and restrictions on dredging activity are summarized in section 4.2, human use impairments. The remainder are summarized below.

PAHs, PCBs, DDE, DDT, mercury, lead, chlordane, dioxins, mirex, dieldrin, and nitrates are all demonstrated to be causing impairment to fish and/or wildlife. As a result, most of these chemicals have already been identified as LaMP pollutants of concern for source trackdown. In particular, PCBs and mercury have been designated as critical pollutants for priority action in the Lake Erie LaMP.

4.3.1 Benthos

Benthos refers to the suite of organisms that live on or in the lake bottom, referred to here as macroinvertebrates. Because macroinvertebrates live in close association with the sediments and are relatively immobile, they are good bioindicators of levels of persistent compounds in the sediments, especially trace metals and organic chemicals (pesticides, petrochemicals, PCBs, PAHs, etc.). Therefore, one of the criteria used for assessing benthic impairment is when toxicity of sediment-associated contaminants at a site is significantly higher than reference controls.

Highly toxic sediments produce profound, but sometimes non-specific, reductions in benthic abundance, richness (numbers of species), and community composition. Lower levels of contaminants may cause sublethal effects in invertebrates, just as they do in vertebrate animals (impairment of growth or development, morphological deformities, chromosomal abnormalities, or production of stress proteins). Contaminant breakdown products are often more toxic than the parent compounds. However, some benthos may tolerate persistent compounds because they lack the ability to break the pollutants down into compounds that can be excreted. Because benthic invertebrates may bioaccumulate these toxic compounds, their body burdens can serve as indicators of the amount of bioavailable contaminants in the environment, and of the transfer potential to predators at higher trophic levels (fishes, birds, etc.). Bioaccumulation factors for some chemicals can be extrapolated to anticipate whether burdens of top predators are likely to approach toxic thresholds.

For the Lake Erie LaMP assessment, the benthic communities found in contaminated sediments may be designated impaired if one or more of the following occur:

- The community is degraded;
- Bioassays using sediment from an area indicate toxicity to benthic organisms;
- Macroinvertebrates collected from the sediments have significantly elevated incidences of deformities or other abnormalities;
- The contaminant burden of benthic animals is great enough that predators may be at risk of bioaccumulating toxic concentrations of the contaminants.

Impairment was assessed in each of six lake zones: tributaries, wetlands, shorelands, embayments, nearshore and offshore. Draft conclusions, by basin and zone, for benthic impairments due to contaminated sediments are summarized in Table 4.5. Benthic impairments that are due to causes other than contaminated sediments are addressed in section 4.4.

Table 4.5 Summary of Benthic Impairments Caused by Contaminated Sediments

Lake Erie Zone	Lake Erie Basin	Type of Impairment
Tributaries	Eastern - Buffalo River	Contaminated sediments; elevated incidence of mouthpart deformities in midges
	Eastern - Grand River, Ontario	Chemical contamination
	Central - Black, Cuyahoga and Ashtabula Rivers	Contaminated sediments
	Western - Detroit, Raisin, Ottawa and Maumee Rivers, Swan Creek	Contaminated sediments
Embayments	Central - Black, Cuyahoga, Ashtabula Rivers	Harbors dominated by pollution tolerant benthos
	Western - Maumee Bay, Toledo Harbor	Contaminated sediments
Nearshore *($\leq$ 5 m depth water depth up to 4 km from shore)*	Western - Detroit and Maumee Rivers	Elevated incidence of mouthpart deformities in midges
Offshore *(> 4 km from shore)*	Western - Detroit River discharge current	Low *Hexagenia* population density appears to parallel discharge current band; this needs to be confirmed with maps
	Western - Monroe	Adult *Hexagenia* collected in 1994 had the highest contaminant burdens (PCBs, other organochlorines, pesticides) of any Lake Erie samples
	Western - Middle Sister Island	*Hexagenia* larvae had high burdens of organochlorines and PAHs

Data gaps

- Most of the identified benthic impairments are in the western basin of Lake Erie because there is almost no data on benthic contaminant burdens in the central and eastern basin. This is an important data gap that must be filled to complete the assessment of Lake Erie benthic health. Scarcity of organisms previously hindered obtaining this information. With the advent of zebra mussels and *Hexagenia* swarms, the biomass is now easily collected, but sample analysis costs are still a barrier.
- Toxicological studies of organisms that prey primarily on benthos are lacking. Therefore, we do not have specific information about the contaminant burdens in benthos at which toxic or sublethal impacts occur to predators. In this assessment to address biomagnification without the above-mentioned data, we determined that if contaminant levels in benthos (lower trophic level) were equal to the contaminant levels in fish (higher trophic level) that trigger a human consumption advisory, the benthos are potentially toxic to top predators.

4.3.2 Fish

Overview

In Lake Erie and its tributaries, mercury, PCBs, lead, chlordane and dioxins are causing fish consumption advisories. PAHs in contaminated sediments are causing fish tumors and other deformities. The purpose of fish consumption advisories is to minimize potential adverse impacts to human health (section 4.2). However, the contaminant data that support the advisories can also be used as a tool to assess fish and wildlife health. For example, contaminant levels in fish are used to develop bioaccumulation factors used in assessing contaminant impacts to fish-eating birds, mammals, amphibians, and reptiles (see section 4.3.3).

The purpose of assessing the prevalence of fish tumors and other physical abnormalities is to use these as an indicator of both environmental degradation of the aquatic ecosystem and as a measure of health impairment to fish populations. However, this assessment of fish health is limited to fish deformities and PAHs, which do not bioaccumulate. Therefore, the potential impacts of bioaccumulative chemicals on other aspects of fish health, such as reproduction, are not covered. This data gap is acknowledged by the LaMP and explained in more detail in the data gaps section below.

The assessment criteria require identification of fish tumor or deformity impairments: a) regardless of whether a specific cause for the tumor has been identified, b) regardless of whether a cause, when identified, is a chemical pollutant and/or carcinogenic, and c) regardless of whether a tumor is a carcinoma. Only data for types of tumors suitable as impairment indicators were used for this assessment (excludes genetically and virally induced tumors). All sites where fish tumor data suitable for indicating impairment existed, and tumor prevalence exceeded rates at least impacted sites in the Lake Erie basin, were classified as impaired as summarized in Table 4.6.

Where brown bullhead tumor impairment occurs, the cause is known to be PAHs. Because brown bullhead are benthic fish and remain in a specific geographic location during their lifespan, tumors are indicative of local sediment conditions. In surveys of other fish species, although the causes of tumor or deformity impairment are unknown, the presence of more mobile fish species points to broader environmental degradation (versus locally contaminated sediments) as the source of the problem.

Table 4.6 Summary of Fish Tumor or Deformity Impairments

Western Basin Nearshore	**Impaired** - in 6 tributaries, the Lake Erie islands, and along the Lake Erie shoreline in 2 Ohio counties.
Western Basin Offshore	No conclusive documentation of impairment (e.g. freshwater drum tumors).
Central Basin Nearshore	**Impaired** - in 13 tributaries, 1 bay, and along the Lake Erie shoreline in 4 Ohio counties.
Central Basin Offshore	No data available to assess impairment.
Eastern Basin Nearshore	**Impaired** - in 1 tributary and 1 bay.
Eastern Basin Offshore	No conclusive documentation of impairment (e.g. freshwater drum tumors).

Research Needs/Data Gaps

During the review of and comment on Lake Erie beneficial use impairment assessments, concern was raised that there was nothing equivalent to the Bird and Animal Deformities or Reproductive Problems assessment to cover the issue of fish reproductive problems due to chemical contaminants. (Fish reproductive problems from causes other than contaminants are covered in the degradation of fish populations and loss of fish habitat assessments.) As a result of this issue being raised, it was decided that a separate report to address this issue would be produced by the LaMP, when resources are available. This report will examine things such as goiterogens, endocrine disruptors, as well as any chemical contaminant related reproductive problems.

There are two issues with the current fish tumors or other deformities assessment: a) the age of tumor incidence data for certain locations, and b) lack of true reference site data. Because funding for fish tumor studies has generally only been available to analyze locations where contaminants are known to be degrading the environment, little attention has been paid to developing data for unimpacted sites. Therefore, data from “least impacted” sites had to be used to assess impairment in Lake Erie. With true reference site data, the magnitude and severity of existing impairment would likely be greater.

In Canada, the Ontario biomonitoring program to assess fish tumor incidence ended in 1996 due to government budget cuts. To address these issues in the U.S., the United States Geological Service (USGS) is currently coordinating a research and monitoring effort, in partnership with a number of principal investigators, to re-evaluate conditions in all the U.S. Areas of Concern (AOCs). One aspect of this project is monitoring the current rate of tumor incidence in Lake Erie tributaries. Data results are expected to be available in phases over the next two to three years. The USGS project, once completed, will provide an update to the information presented in this assessment report and is also expected to provide some new reference site data. At a minimum, reference site data will be available from the Huron River in Ohio.

Despite these attempts to update information for the U.S. AOCs, there is still a general lack of knowledge about the extent of the occurrence of tumors in fish from Lake Erie, as well as the rest of the Great Lakes, in species other than drum and bullhead. Comprehensive data on fish deformities in other species found along the Lake Erie shoreline exist only for Ohio. Specific data gaps are as follows:

- Data results from systematic evaluation of fish species, other than bullhead, have been provided to the LaMP only for the Ohio tributaries and Lake Erie shoreline. The causes of elevated incidence rates of fish tumors and/or deformities in these other species are unknown.
- Most of the existing information about tumor occurrence deals with the fish of the harbor, bay, and tributary areas. Tumors or deformities in fish of the open lake have been studied much less.
- Studies that use a standardized sampling method are needed so that studies in various states and lakes are comparable. For instance, a statistically valid sample of the most abundant length classes of adult fish of a given species needs to be used instead of including all length classes.
- And finally, studies that characterize other components of the ecosystem inhabited by tumor-bearing fish might indicate the value of tumor prevalence as a predictor of ecosystem health.

4.3.3 Wildlife

Toxicological wildlife survey data are used throughout the Great Lakes to confirm the presence of deformities or other reproductive problems in sentinel wildlife species in a particular location. Therefore, by definition, the presence of these problems is enough evidence to confirm that impairment is occurring and is a good indicator of both wildlife health and potential adverse impacts due to contaminants. This assessment is not intended to assess population-wide impairments. Those issues are covered in the degradation of wildlife populations assessment (see Table 4.9).

Because wildlife toxicology surveys are often designed to determine conditions in the Great Lakes basin as a whole, this assessment varies from others in the amount of Lake Erie specific data available and its ability to report results by Lake Erie basin. In addition, the Lake Erie basin populations of some of the species examined such as bald eagle and colonial waterbirds nest primarily in the western basin. Others such as the river otter were extirpated from the Lake Erie basin prior to the 1900s and have only recently been reintroduced by wildlife management agencies. The most abundant data are available for Lake Erie bald eagle and herring gull populations that have been surveyed annually since 1980 and the early 1970s, respectively.

A combination of lowest observable effect concentrations (LOECs), population recovery objectives, and physiological biomarkers was used to establish the scientific weight of evidence for impairment. Ecoepidemiological criteria were used to establish cause-effect linkages, where possible. Reproductive, deformity, and physiological impairments are identified and associated with chemical causes, where known, in Table 4.7. These results indicate that some type of impairment is either clearly or likely occurring in all groups assessed, except for tree swallows. As noted below, tree swallows are very resistant to the effects of chemical contaminants, and may therefore be a poor indicator species.

As noted earlier, per the IJC listing criteria, this assessment is not required or intended to determine whether population-wide effects are occurring due to the identified impairments. Reproductive effects do not immediately or always translate into population effects. For example, if a population is near its carrying capacity (point at which species is in equilibrium with its environment), then there may not be enough resources (food, nesting habitat, etc.) for all young to survive to reproductive age. Hence, up to a point, a decrease in production of young due to a contaminant may not affect adult population size because many young would have died anyway. However, if the population is below its carrying capacity, a decrease in production of young may prevent the population from reaching carrying capacity. In this situation, the impairments summarized in Table 4.7 can become more significant when all stressors to a particular species group are summed (contaminants, habitat loss, exotics, etc.). It is interesting to note that the results of the degradation of wildlife populations assessment for these same groups of animals conclude that impairment is also occurring at the Lake Erie basin sub-population level.

Table 4.7 Summary of Bird and Animal Deformity or Reproductive Impairments

Species/Species Group	Impaired?	Type of Impairment	Likely Cause*	Notes
Bald Eagle	**Yes**, observed; exposure above effect levels	Reproductive & Deformity	**R**-PCBs, dieldrin, DDE **D**-PCBs	Extent of impairment is probably obscured by hacking/fostering and immigration from less contaminated inland territories
Colonial Waterbirds (herring gulls, double-crested cormorants, common and Caspian terns)	**Yes**, observed in herring gulls; exposure above effect levels in herring gull, cormorant, and common tern eggs	Reproductive, Deformity & Physiological-immune system, reproductive organs, thyroids, liver enzymes, vitamin A, & porphyrins**	**R**-PCBs and possibly other chemicals **D**- PCBs **P**- PCBs, other organo-chlorines	* Cause of recent reproductive failures of herring gulls on W. Sister Is. may include PCBs, microcystin, and (or) other factors * Tree nesting cormorants are hard to study, but contaminant concentrations are among highest in Great Lakes and are likely associated with embryonic mortality and deformities *Although Caspian terns have attempted to colonize Lake Erie as recently as 1996, they are still too rare in the basin for field study
Tree Swallow	Not impaired			Significant Organochlorine exposure; resistance to effects may make swallow a poor indicator species compared to other insect-eating songbirds
Mink	Likely; PCBs in food above effect levels	Likely Reproductive and Physiological	**R** - PCBs **P** - no data	
Otter	Insufficient data, but likely based on predicted high levels of exposure	Likely Reproductive	**R**- PCBs	Too rare in Lake Erie basin for study as they have just recently been re-introduced.

Species/Species Group	Impaired?	Type of Impairment	Likely Cause*	Notes
Snapping Turtle	Likely - not observed, but exposure at some Ohio sites above effect levels	Likely Reproductive, Deformity, Physiological	**R** - PCBs, other organochlorines **D** - PCBs, other organochlorines **P** - organochlorines	
Eastern Spiny Softshell Turtle	**Yes**, observed; exposure above effect levels	Reproductive	**R** - PCBs, other organochlorines	
Frogs/Toads	Likely (see notes)	Likely Reproductive	**R**-DDE, nitrates	Nitrate concentrations in Lake Erie watershed often exceed lethal and sublethal concentrations for amphibians studied in laboratory experiments
Mudpuppies	**Yes**, observed	Deformity	**D**- PAHs and organo-chlorines	

* R= Reproductive impairment; D = Deformity Impairment; P = Physiological Impairment

** Porphyrins - the liver synthesizes heme for hemoglobin and certain enzymes. Some organochlorines block this process by causing the accumulation of highly carboxylated porphyrins.

Nitrates

Nitrates are nutrients and do not bioaccumulate. However, at higher concentrations they have been shown to cause effects to amphibians that are similar to those caused by toxic contaminants. Because less research and monitoring data are generally available for amphibian populations as a group, the mechanisms for the observed biological effects of nitrates are not as clearly defined as those for other organisms. A short summary of what is known is provided below.

A review by Rouse *et al.* (1999) evaluated the risk of direct and indirect effects of nitrate on amphibian populations. This review used a simple comparison of known environmental nitrate concentrations in North American waters to nitrate concentrations known to cause toxicity in a laboratory setting to amphibian larvae and other species that play an important role in amphibian ecology.

Lethal and sublethal effects in amphibians are detected in laboratory tests at nitrate concentrations between 2.5 and 385 mg/L (Table 4.8). Amphibian food sources such as insects and predators such as fish are also affected by elevated levels of ammonia and nitrate in surface waters (Rouse *et al.*, 1999). This may have important implications for the survival of amphibian populations and the health of food webs in general.

Table 4.8 Toxicity of Nitrate to Amphibians (Rouse *et al.,* 1999)

Species	Stage	Endpoint (mg/l)	Concentration of Nitrate
Bufo americanus	Tadpole	96h-LC50	13.6 & 39.3
Pseudacris triseriata	Tadpole	96h-LC50	17
Rana pipiens	Tadpole	96h-LC50	22.6
Rana clamitans	Tadpole	96h-LC50	32.4
P. triseriata	Tadpole	Developmental	2.5-10
R. pipiens	Tadpole	Developmental	2.5-10
R. clamitans	Tadpole	Developmental	2.5-10
Bufo bufo	Tadpole	96h-LC50	385
Bufo bufo	Tadpole	Developmental	9
Bufo bufo	Tadpole	Death	22.6
Litoria caerulea	Tadpole	Developmental	9
Litoria caerulea	Tadpole	Death	22.6
*Rana temoraria**	Adult	EC50-paper	3.6 g/m^2
Rana temoraria	Adult	EC50-soil	6.9 g/m^2

* Frogs were placed on moist paper or soil spread with ammonium nitrate granules

LC50=lethal concentration required to kill 50 percent of the test population within 96 hours

EC50=lethal concentration for 50% of the population

Environmental concentrations of nitrate in surface waters in agricultural watersheds in southwestern Ontario and US states in the Lake Erie watershed ranged from 1 to 40 mg/L. Of 8000 water samples from rivers in the watersheds of Lake Erie and St. Clair in the Canadian Great Lakes and in US states in the Lake Erie watershed, 19.8% had nitrate levels above 3 mg/L. This concentration was known to cause physical and behavioral abnormalities in some amphibian species in the laboratory (Rouse *et al.,* 1999). A total of 3.1% samples contained nitrate levels that would be high enough to kill tadpoles of native amphibian species in laboratory tests (Rouse *et al.,* 1997).

Research Issues/Data Gaps

Programs and funding for monitoring contaminant concentrations and assessing their biological effects have declined in recent years. Maintenance of these programs is essential for filling the information gaps described in Table 4.7, assessing recovery from impairment, and detecting the emergence of new problems. Specific survey and monitoring needs are outlined below.

- Most of the major contaminants considered in this assessment are organochlorines, because they caused past and current reproductive impairments and population-level effects. More environmental data are available for this class of chemicals than others. However, many other newer industrial chemicals and pesticides are released into the Lake Erie ecosystem in large quantities. Few biomonitoring studies have examined the concentrations and biological effects of these chemicals in Lake Erie wildlife. Recent advances in laboratory and field toxicology have shown that some of these chemicals (e.g., nonylphenol, bisphenol A, atrazine, aldicarb) are able to disrupt the function of the endocrine, immune, and nervous systems, even with low level exposure during development.
- Due to improvements in the health of national populations of bald eagle in both the U.S. and Canada, the level of effort to monitor or band Lake Erie bald eagles has decreased in recent years. However, for the Lake Erie subpopulation, contaminant impacts are still affecting the recovery of the overall population. Therefore, it is important to continue studies of reproductive success, deformities, and contaminant concentrations in blood and eggs. It is also important to consider continuing banding/color-marking studies to allow tracking of individual eagles from the territories where they are raised to the territories where they breed. Up until about two years ago, this was done across the entire lake. Today this type of more intensive monitoring is more spotty and declining due to declining funding. Studies of recruitment patterns will be essential for answering questions about the high turnover rate of adult eagles breeding on the Lake Erie shoreline, the survival and reproductive success of eagles exposed developmentally to contaminants from Lake Erie, and the rate of immigration from inland areas to the Lake Erie shoreline.
- The cause of the reproductive impairment in herring gulls on West Sister Island requires further investigation. Toxicologically significant concentrations of microcystin toxin have been found in the livers of one herring gull from West Sister Island and a number of Caspian tern chicks from Saginaw Bay, which bears some similarity to western Lake Erie in terms of primary productivity and PCB concentrations. The accumulation of microcystin toxin in colonial waterbirds is an emerging issue that deserves further study. Other potential causes of the reproductive failure include PCB-induced wasting syndrome, infectious disease, or some interaction among these factors.
- A formal deformity survey in colonial water birds is needed to better estimate the rate of deformities.
- Birds such as tree swallows that eat emergent aquatic insects can accumulate high concentrations of organochlorines and other contaminants. Although studies of Lake Erie tree swallows from the eastern and central basins have shown only a few biochemical effects and no reproductive effects, biologically significant impacts are possible in more sensitive species, especially in the western basin where organochlorine concentrations are higher. Such studies should be initiated.
- Little is known about the potential exposure of diving ducks to contaminants through consumption of zebra mussels. A significant proportion (52%) of diving ducks (scaup, goldeneye, bufflehead, scoter, and old-squaw) had zebra mussels in their gizzards at the time of collection from Lake Erie (Hamilton and Ankney, 1994). The potential for physiological effects following consumption of contaminated zebra mussels has not been studied.
- Better information is needed for mink and otter in the following areas: population surveys, tissue residues, and contaminant concentrations in food. The Canadian Wildlife Service has initiated a mink carcass collection to take place from 1999-2001 within the Canadian Lake Erie watershed. Trapper-caught carcasses from Lake Erie marshes and inland tributaries will be analyzed for contaminants, and examined histopathologically and morphologically. Measurements of reproductive organs will be made to determine possible contaminant effects on reproductive development. Collections of mink carcasses and potential food items from two Lake Erie marshes were made in 1998, and will be analyzed for carbon and nitrogen stable isotope ratios, a technique that provides

information on the diet of marsh-living mink. Ongoing monitoring of mink populations in shoreline marshes using track censuses is planned.

- Few studies exist that examine both the levels and associated effects of contaminants on reptiles living in the Lake Erie watershed. The few studies that exist for Lake Erie have primarily examined contaminant concentrations in tissues and eggs. Contaminant concentrations in Lake Erie water snakes from Pelee Island are high enough to justify a study of health and reproductive effects. The Canadian Wildlife Service, World Wildlife Fund and Upper Thames River Conservation Authority recently initiated such a study.
- Contaminant concentrations in the threatened eastern spiny softshell turtle and the corresponding low rates of egg hatching in the Lake Erie basin suggest that further investigation of contaminant effects is warranted. The Canadian Wildlife Service, World Wildlife Fund and Upper Thames River Conservation Authority recently initiated such a study.
- Further investigation of contaminant levels and effects in the common snapping turtle is warranted in coastal wetlands of Lake Erie, especially the western basin and marshes in the U.S. Hatching success and deformity rates should be examined. Other endpoints, such as differential effects on males versus females and behavioral effects in snapping turtles from Lake Ontario and the St. Lawrence River, are being studied by the University of Guelph and the Canadian Wildlife Service. These endpoints could be examined in Lake Erie populations in the future.
- Data is needed about the sensitivity of amphibian eggs, larvae and adults to DDT concentrations presently occurring in water and the food web of coastal wetlands, especially in Point Pelee National Park.
- The sensitivity of mudpuppies, frog tadpoles, and adult frogs to TFM use in the Great Lakes has been noted (Gilderhus and Johnson, 1980; NRC, 1985; Matson, 1990; Weisser *et al.*, 1994). The lampricide TFM is used to control the exotic sea lamprey that otherwise would impair populations of lake trout and other species (see Section 4.4.2.2). There are conflicting opinions about the significance of this sensitivity and its implications for potential impairment. Therefore, the impact of TFM on amphibian populations needs to be assessed by monitoring populations of mudpuppies and other amphibians pre- and post-treatment. These studies need to establish the significance of any mortality to these populations in treated streams and in the Lake Erie basin as a whole. From a reproductive standpoint, it is particularly important to determine if TFM has greater impacts on certain age classes and/or egg-bearing females.
- Nitrate concentrations in agricultural watersheds of Lake Erie (3.1 % of water samples) are high enough to exceed the LC50 or sublethal effect (19.8% of water samples) on amphibian tadpoles of various species. However, these predictions are based on laboratory-based studies and need to be tested in wild populations.

4.4 Ecological Impairments

Ecological beneficial use impairments are intimately interconnected, and in Lake Erie include: degraded fish, wildlife, phytoplankton and zooplankton populations; loss of fish and wildlife habitat; eutrophication or other undesirable algae; degraded benthos; fish tumors or other deformities; and bird or animal deformities or reproduction problems. Therefore, the status of these beneficial use impairments needs to be integrated to develop a more comprehensive understanding of stressor impacts to the system as a whole. Fish tumors or other deformities, bird or animal deformities or reproduction problems, and benthic impairments caused by chemical contaminants are covered in detail in section 4.3, but are also mentioned in this section because dysfunction in the ecosystem is caused by contaminants as well as other stressors. Table 4.9 summarizes both the types of impairment and impairment conclusions for the noncontaminant related ecological impairments.

The ecological beneficial uses were assessed in relation to historical conditions, existing management goals and objectives, out-of-system references (where available), and recent concerns, as applicable. Impairments occur to all of the beneficial ecological uses of the lake. To fully understand the causes of impairment as outlined below, it must be understood that population impairments are often a subset of habitat impairments. Therefore, this ecological use synthesis starts by addressing habitat to document the causes and extent of impairment. The underlying causes (stressors) of the habitat degradation are examined. Habitat impairment information is grouped by stressor because each stressor generally affected a broad range of habitat types.

Population information is organized by impairment results, rather than by stressors causing impairment, because population impairments integrate across trophic levels to the whole ecological community. One of the criteria for determining habitat impairment is inability to support healthy benthos, plankton, fish, and wildlife populations. So, when the status of these populations is summarized, lost and degraded habitat is one of the key causes of population impairment.

The key reasons for habitat impairment, called primary stressors, are hydrology changes associated with land use, nutrient and sediment loads, invasion of non-indigenous species, and contaminants. All of these primary stressors are the result of human use of the Lake Erie environment. Due to the adverse impacts of primary stressors on the Lake Erie environment, some key secondary stressors have also emerged. For example, due to the irreversible loss of large areas of Carolinian forest habitat, black-crowned night herons and egrets are primarily restricted to breeding on the Lake Erie islands in the western basin. Here they compete for habitat with the booming double-crested cormorant population. The cormorant population is present because of protection from human disturbance and an abundant food supply of exotic pelagic fish (alewife, shad, smelt). The cormorant guano is killing the trees in which herons and egrets nest. In this case, the primary stressor is changing land use that led to the loss of mainland habitat. The secondary stressor is the impact of the cormorant population on the remaining island habitat. Therefore, when examining causes of impairment and means of rehabilitation, it is important to understand the sequential interactions of stressors as well.

Table 4.9 Summary of Ecological Impairments

Impairment	Impairment Conclusions	Types of Impairment	Causes of Impairment
Degradation of Phytoplankton and Zooplankton Populations*	**Impaired** - entire *eastern basin*; lake effect zones of certain *western and central basin* tributaries	*PHYTOPLANKTON-eastern basin*-total standing crop and photosynthesis are below the potential set by P loading in the nearshore; loss of keystone species; loss of trophic transfer to *Diporeia* *ZOOPLANKTON-eastern basin*-loss of dominant cold-water species; *Eastern and west-central basins*- reduction in mean size points to potential impaired trophic transfer; *west central basin - Bythotrephes* acts as an energy sink; *western and central basin* lake effect zones- habitat loss and degradation	Zebra and quagga mussel grazing; high planktivory
Degradation of Fish Populations*	**Impaired** in *all basins* (species impaired vary by basin)	unmet fish population objectives**; loss of spawning/nursery area; loss of population diversity; rare, threatened, endangered and special concern species; reduced predatory function; unnaturally high fish community instability; inefficient use of food web energy	habitat loss and degradation; non-indigenous species (exotics); loss of forage fish availability; overexploitation; loss of native stocks/species, particularly keystone predators

Impairment	Impairment Conclusions	Types of Impairment	Causes of Impairment
Loss of Fish Habitat*	**Impaired** in tributaries, shorelands, and nearshore of *all basins* (note-nearshore includes entire western basin area);	unmet fish habitat objectives**; loss of habitat diversity & integrity; loss of spawning/nursery areas; barriers to migration; changes in stream temperature, water quality, and hydrology; high turbidity; loss of aquatic vegetation; changes to benthic species composition;	destruction and draining of wetlands; dams, dikes, dredging/channel modifications, water taking; streambank/ shoreline filling and hardening; sediment/chemical contaminant/ nutrient loadings; navigation/ recreational boating activities; exotics (carp, purple loosestrife, *Phragmites*); *Cladophora* fouling (eastern basin nearshore)
Degradation of Wildlife Populations	**Impaired** in *all basins* detailed case studies are being prepared for 20 species or wildlife groups (birds, mammals, amphibians and reptiles) to illustrate the key impairment issues affecting the larger group of wildlife species that use the Lake Erie environment	unmet wildlife population objectives**; population fragmentation, isolation, and instability; loss or reduction in species indicative of quality habitat; loss of source populations; rare, endangered , threatened, and special concern species; accelerated rates of parasitism/ predation; competition between wildlife/nonwildlife uses of a given habitat ; changes to ground temperature and moisture conditions in forested areas; loss of travel lanes; loss of range/area-sensitive species (e.g. –amphibians & reptiles, rails, bitterns, sedge wrens, bald eagle)	fire suppression; logging; destruction and draining of wetlands; high water levels, storm surges; dredging/channel modifications, water taking, streambank/shoreline filling, hardening & backstopping; sediment/chemical contaminant/nutrient loadings; navigation/boating activities; exotics (zebra mussel, carp, purple loosestrife, *Phragmites,* garlic mustard, Eurasian milfoil, hybrid cattail, mute swan, gypsy moth, Dutch elm disease, chestnut blight)
Loss of Wildlife Habitat	**Impaired** in *all basins* 16 major habitat types were assessed. 13 were impaired in all Lake Erie jurisdictions where they occur (open lake, islands, sand beach/cobble shore, sand dunes, submerged, floating and emergent macrophytes, wet meadow, shrub swamp, mesic prairie, upland marsh, mesic and swamp forests)	unmet wildlife habitat objectives**; habitat fragmentation and loss of niches; loss of diversity and integrity; population demands exceed available habitat (e.g.- colonial waders that use the Lake Erie Islands); loss of stopover habitat along migratory corridors (birds, butterflies, bats); loss of cover for protection from predation; loss of or accelerated succession patterns; loss of area available for habitat expansion; loss of buffer functions between one habitat type and another; loss or reduction in quantity/quality of nesting/denning areas; loss or reduction in quantity/quality of food sources	fire suppression; logging; destruction and draining of wetlands; high water levels, storm surges; dredging/channel modifications, water taking, streambank/shoreline filling, hardening & backstopping; sediment/chemical contaminant /nutrient loadings; navigation/boating activities; exotics (zebra mussel, carp, purple loosestrife, *Phragmites,* garlic mustard, Eurasian milfoil, hybrid cattail, mute swan, gypsy moth, Dutch elm disease, chestnut blight)

Impairment	Impairment Conclusions	Types of Impairment	Causes of Impairment
Degradation of Benthos	**Impaired.** *eastern basin*-offshore waters; *central basin*-tributary, shoreland, nearshore and offshore waters; *western basin*-tributary, shorelands, offshore waters	Degraded benthic community (composition and interactions among components) compared to reference conditions; Dominant species indicate degraded environment; Keystone species absent or nearly gone: **all basins*-unionid mussels, *Gammarus* amphipods; **east & central basins-Diporeia* amphipods; **east and western basins* - fingernail clams; **middle* of western basin-*Hexagenia* (mayflies), see *Table 4.5;* unmet objectives for benthic density, biomass or productivity**; toxicity to benthic organisms (section 4.3.1); elevated incidence of deformities or other abnormalities (section 4.3.1); contaminant burden is high enough that predators may be at risk of bioaccumulating toxics (section 4.3.1)	contaminated sediments, non-indigenous species or exotics (zebra mussel, round goby, etc.), loss and degradation of habitat particularly in wetlands
Eutrophication or Undesirable Algae*	**Impaired** - Maumee Bay, lake effect zones of Maumee/Ottawa Rivers, *western basin*; nearshore and river mouth areas of Canadian *eastern basin* Potentially impaired – lake effect zones of certain Ohio tributaries, *western and central basins*; Rondeau Bay and nearby nearshore and river mouth areas, Canadian *central basin*	Excessive *Cladophora* (see Degradation of Aesthetics impairment conclusions), degraded fish communities in lake effect zones of certain tributaries, P levels above Canadian guidelines in tributaries	Phosphorus

* More detailed technical information is available on-line at http://www.epa.gov/glnpo/lakeerie/buia/index.html for each assessment with an asterisk

** For a discussion of existing objectives and their relationship to Lake Erie LaMP ecosystem objectives, see section 4.1.

4.4.1 Habitat Impairments

4.4.1.1 Introduction

The IJC very broadly defined habitat as the "specific locations where physical, chemical and biological factors provide life support conditions for a given species." Specifically, the IJC indicated that "habitat impairment occurs when fish and/or wildlife management goals have not been met as a result of loss of fish or wildlife due to a perturbation" of the habitat. Management goals have been developed for birds (North American Waterfowl Management Plan (NAWMP), National Shorebird Plan, and Partners in Flight -Flight Plan) and fish (Lake Erie Fish Community Goals and Objectives). In addition, when the IJC developed listing criteria for determining benthic impairment, they included a recommendation that ecosystem health objectives be developed using benthic community structure. This recommendation has been implemented by a number of Lake Erie researchers (particularly for keystone species) and the *objectives* have become widely accepted in scientific circles, even though they do not yet reside in any formal management plan. For other organisms, key indicator species and/or community structure were examined.

To assess the quality of the habitat in the Lake Erie basin, the basin was divided into 18 regions of similar physical, chemical and biological structure. The present evaluations were based not only on the ability of the present habitat to support fish, wildlife, plankton and benthic populations (ecological function) and on local and lakewide objectives as prescribed by the IJC, but also on historical records/out-of-system references, and recent concerns. Table 4.10 summarizes our present information linking stressors and habitats. Loss of natural area to human use (i.e. agriculture, industry, housing) is an impairment in all Lake Erie basin upland habitat types, and extends shoreward to include wet meadows, emergent macrophytes, interdunal wetland and unconsolidated shore bluffs. So much of the original habitat has been lost that fragmentation of habitat and the small size of remaining habitat impaired mesic forest, swamp forest, shrub swamp, mesic prairie, wet meadow, and wetland complexes. Other stressors are further degrading the remaining natural habitat.

4.4.1.2 The Habitat Continuum

Habitat degradation in the Lake Erie basin is due to a number of stressors, acting in concert. Even if the most critical stressor were alleviated, complete recovery would not occur. Remediation will likely require improvement in a number of areas. Table 4.10 summarizes our understanding of the relationship between stressors, habitat impairment, and impacts to populations of benthos, fish and wildlife. Stressors are listed vertically by category (altered hydrology, changing land use, and other) and the major habitat types assessed in the Lake Erie basin are listed horizontally. Habitat definitions are outlined in Table 4.11. Where X is used, the applicable stressor affects all fish, benthos and wildlife. Where a stressor only affects the habitat of fish, benthos, or wildlife the letter F, B or W was used instead of X. Where there is nothing in a cell, it means that the particular stressor does not significantly affect that particular habitat in the Lake Erie basin. In addition to integrating this information, the table is designed to provide a preliminary tool for developing an action agenda.

The 18 habitat types listed in Table 4.11 form a continuum of changing physical, chemical and biological structure along gradients of water/moisture, light penetration, and substrate type. In sheltered aquatic areas, habitat progresses from open water to submerged macrophytes, floating macrophytes, emergent macrophytes and then wet meadow and shrub swamp or mesic prairie as water depth and flooding decrease and light becomes more available. In exposed aquatic areas, the nearshore habitats progress from sand or cobble substrates below water to beaches, interdunal wetlands in the sheltered hollows behind the beach or foredunes, and sand dunes. These two suites of nearshore habitats absorb the wave energy during storm events, protecting the upland regions from the more severe flooding and erosion events that are present today in comparison with historical conditions. Degradation of the beach and wetland complexes has decreased their ability to absorb the force of storms and is considered a cause of impairment of the dunes, wet meadows, mesic prairie and forests. On land, the dunes and mesic prairie give way to mesic forest. In the uplands, swamp forest, marshes, bogs, fens and vernal ponds develop in depressions and kettles. A similar progression of habitats radiates out from the larger open water and marsh areas and sheltered regions of tributaries. The floodplains of the tributaries develop shrub swamp and swamp forest.

The interconnectedness of the habitats in the Lake Erie basin means: (1) that degradation in one habitat has consequences for adjacent or downstream habitats, and (2) that stressors generally affect a range of similar or adjacent habitats across a gradient. Some stressors, such as contaminants and loss of habitat area, affect community function in a broad range of habitats. Because habitats are highly interconnected, many species do not spend their entire life cycle in one habitat. For example, many species of birds that are habitat specific during the nesting season utilize a completely different set of habitats during the migration periods and may winter in entirely different regions of the continent. Another example is northern pike that live among submerged macrophytes as adults, but breed in flood pools associated with tributaries. Their young live in the emergent vegetation. Turtles and snakes that live in marshes and swamps lay their eggs in nearby forest and beach ridges. To support intact fish and wildlife communities, it is important for the whole range of habitats to be present and naturally functional.

Table 4.10 A Summary of the Stressors Affecting the Habitats in the Lake Erie Basin

Habitat Zone	Aquatic Habitat			Shore Habitat			
Stressor/Habitat Type	Open Water Offshore	Open Water Nearshore	Tributaries*	Islands	Sand Beaches/ Cobble Shore	Unconsolidated Shoreline	Interdunal Wetland
Altered Hydrology							
Altered ground water -wells, logging			X				
High water levels -erosion, flooding		X		W	W	W	W
Lack of along shore sand movement		X			W		W
Tributary flow		X	X				
Stream channelization		X	X				
Dams -sediment, water, barrier		X	X		W		
Draining			X				W
Dredging	B, F	X	X		W		X
Entrainment		F					
Heated Effluent		X					
Changing Land Use							
Conversion to human habitat (e.g.farm)		X	X	X	W	W	W
Degradation of adjacent habitat		X	X		W		W
Fire suppression							
Nutrient addition	B	X	X				
Increased sediment loads		X	X				W
Hardening/development of shoreline		X	X	W	W	W	W
Backstopping/dikes		X	X		W		W
Quarrying/mining/gas & oil wells	Possibly	W	X	W			
Logging			X				
Other							
Exotics	Quagga?	Carp	Carp	Dreissenid s.		NNP	Carp, NNP
Contaminants	X	X	X				
Cormorants/Deer				Corm.			
Loss of large mammals							
Direct human use of natural habitat (e.g. boating, hiking)		F,W	X	W	W		W

NNP = non-native plants; **MS** = mute swan; **Corm.** = cormorant; *Tributary habitat includes floodplain forests and certain swamp forests.

Habitat Zone	Shore Habitat	Nearshore Habitat			Upland Wetland			
Stressor/Habitat Type	Sand Dunes	Submerged Macrophytes	Floating Macrophytes	Emergent Macrophytes	Wet Meadow	Mesic Prairie	Shrub Swamp	Bogs & Fens
Altered Hydrology								
Altered ground water -wells, logging	W			W	W	W	W	W
High water levels -erosion, flooding	W	W	W	W	W		W	
Lack of along shore sand movement	W							
Tributary flow		W	W	W			W	
Stream channelization		W	W	W	W	W	W	W
Dams -sediment, water, barrier								
Draining	W	W	W	W	W	W	W	W
Dredging		X	X	X	X			
Entrainment								
Heated effluent								
Changing Land Use								
Conversion to human use (e.g. farm)	W			W	W	W	W	W
Degradation of adjacent habitat	W	W	W	W	W	W	W	W
Fire suppression				W	W	W	W	W
Nutrient addition		W						X
Increased sediment loads		W	W	W	W		W	X
Hardening/development of shoreline	W	W	W	W	W		W	
Backstopping/dikes	W	W	W	W	W		W	
Quarrying/mining/gas & oil wells								W
Logging								
Other								
Exotics	NNP	Carp, NNP, MS	NNP, Carp	Carp, NNP	NNP	NNP	Carp,NNP	NNP
Contaminants								
Cormorants/deer	W				W	W	W	W
Loss of mammals					W	W		
Direct human use of natural habitat (e.g. boating, hiking)	W		W	W				

NNP = non-native plants; **MS** = mute swan; **Corm**. = cormorant

Habitat Zone	Upland Wetland	Uplands	
Stressor/Habitat Type	Upland Marsh	Mesic Forest	Swamp Forest
Altered Hydrology			
Altered ground water -wells, logging	W	W	W
High water levels -erosion, flooding			W
Lack of along shore sand movement			
Tributary flow			W
Stream channelization			W
Dams -sediment, water, barrier			
Draining	W		W
Dredging	W		W
Entrainment			
Heated effluent			
Changing Land Use			
Conversion to human use (e.g. farm)	W	W	W
Degradation of adjacent habitat	W	W	W
Fire suppression	W	W	W
Nutrient addition	W		
Increased sediment loads	W		W
Hardening/development of shoreline			
Backstopping/dikes			W
Quarrying/mining/gas & oil wells		W	
Logging		W	W
Other			
Exotics	Carp, NNP	NNP	NNP
Contaminants			
Cormorants/deer	Deer	Deer	Corm., Deer
Loss of mammals			
Direct human use of natural habitat (e.g. boating, hiking)	W	W	W

NNP = non-native plants; **MS** = mute swan; **Corm**. = cormorant

Table 4.11 Definitions for Lake Erie Habitats

Habitat	Definition
Islands	With the exception of Mohawk Island, primarily limited to the western basin of Lake Erie. Permanent islands with rock bound shores below dolomite or limestone cliffs. Due to the moderating effects of surrounding lake waters, the climate of the islands has a greater range in annual mean temperature, less precipitation, smaller range of daily temperature, and a longer frost-free season then the neighboring mainland.
Sand Beaches/Cobble Shore	Temporary open shorelands controlled by shifting sands and fluctuating water levels. Composed of rock fragments ranging from fine sand to large boulders. Devoid of or have minimal vegetation.
Unconsolidated Shoreline	Restricted to the eastern and central basins. Bluffs consisting of a rock or clay base with a thin topsoil layer along the top.
Interdunal Wetlands	An integral component of the marsh complex and the wetlands closest to the lake proper. Formed behind the active shoreline when lake levels have been stable enough to provide elevated dune areas. Wet pockets behind the foredunes or beaches and lakeward of the inner dunes or ridges.
Sand Dunes	Formed by deposits of sand and gravel along the lake shore in areas that are no longer under the effect of the active wave zone. Three communities are found in the Lake Erie basin: a) grassland dune complexes; b) wooded beach ridge; and c) the sand barrens found on ancient beach ridges.
Submerged Macrophytes	Occurs in marsh and open lake settings. Characterized by pondweeds, milfoils, coontail, wild celery, and bladderworts that depend on water pressure/buoyancy for support of their thin, pliable stems.
Floating Macrophytes	A transition from open water habitat to emergent marsh vegetation. Occurs in shallow, protected water within streams and coastal marshes. Dominated by rooted plants with floating leaves such as water lily, spatter-dock, water-lotus, water smartweed, and floating-leaved pondweeds.
Emergent Macrophytes	Consists of 2 community associations: a) robust emergents (cattail and hardstem bulrush) occurring lakeward, and b) narrow-leafed emergents (bulrushes, smartweeds, millets, burreed, rice-cutgrass, wild rice, etc.) occurring shoreward. Survive best in stable water levels, but can tolerate fluctuations for short periods.
Wet Meadow	Occurs as a band of vegetation in a transition zone above normal water levels. Soil is moist and may be inundated for a period of time sufficient to reduce the establishment of woody vegetation. Dominant species include bluejoint grass, northern reed grass, slough grass and sedges.
Mesic Prairie	A series of tall and short-grass prairie complexes governed by water availability. Historically fire prevented this habitat from succeeding to wooded habitat.
Shrub Swamp	Distinct from marsh in being dominated by woody vegetation (pussy and sandbar willow, swamp rose, meadow-sweet, silky dogwood, and buttonbush). Generally occur in glacial kettles or around the margins of lakes or marshes. Highly dependent on natural hydrology.
Bog and Fens	Bogs are acidic, peat-accumulating, wetlands with as many as 5 distinct vegetative zones. Fens are also peat accumulating wetlands, where mineral rich (alkaline) spring water comes to the surface, and typically have a marl zone dominated by sedges. Generally bogs and fens are successional habitats that naturally advance to upland habitats in the absence of intervention.
Upland Marsh	Found in low areas of the upland landscape in kettle lakes or pothole-type wetlands. All portions of the coastal wetland complex can also occur in upland marshes.
Mesic Forest	Mature stage of the deciduous forest consisting of oak-hickory and beech-maple communities. Historically, fire was a key controlling factor of this habitat type.
Swamp Forest	Consists of floodplain forest and deciduous swamp forest. Floodplain forests occur with stream and river channels which are at least periodically flooded and common species include silver maple, cottonwood, sycamore, black willow, green ash, box elder, and Ohio buckeye. The typical dominant species of swamp forest include red and silver maple, black ash, and swamp, white and pin oaks.

Tributaries provide an excellent example of the importance of the health, inter-dependence, and connectivity of adjacent habitats frequently emphasized in the beneficial use assessments (see Figure 4.1). Tributary flow regime (the magnitude, timing, duration, frequency, and rates of change of water movements within a watershed) is intimately connected with the watershed tablelands. Formerly, natural drainage patterns through wet forest and meadow habitat water retention areas controlled the amplitude and frequency of spring floods and maintained summer base flows. Cultural land use practices associated with settlement, deforestation, and agriculture increased drainage efficiency.

The amplitude and frequency of spring flooding in basin tributaries increased, as well as the amount of physical energy entering the stream courses. Due to accelerated spring run-off with reduced groundwater recharge, summer base flows were reduced. The draw down of the water table for human use has reduced the flow of spring water to certain rivers in eastern Ontario. This has further reduced summer base flow in these systems and impaired the spawning reaches of cold-water anadromous fish, such as trout.

The damming of lake basin tributaries is almost universal in scope. Dams alter the connectivity of stream systems and are barriers to migrations and other ecological interactions. Dams with sediment trapping abilities alter the physical hydrology and sediment dynamics in downstream reaches. Floodplains provide periodic connectivity between stream channel habitats and those habitats in these aquatic/terrestrial transition zones. Native terrestrial and aquatic species that are dependent on floodplain habitats evolved in these unique systems under natural flow regime conditions. Floodplains also provide for retention and assimilation of sediments, nutrients, and contaminants that are carried in the stream flow. The loss of assimilation capacity in tributary floodplains and their associated wetland complexes affects environments in inter-dependent nearshore zones (e.g. regions used by larval fish) and diverts the water, nutrients and sediments into the remaining wetlands, causing degradation of the wetland complex and nearshore regions of the lake.

Tributaries and their watersheds naturally provide a certain level of nutrients and sediments to the swamp forest in the floodplain, the lake and the wetland complexes. When the natural pattern of sediment and nutrient flow is altered, problems develop. Dams are a major reason for fish habitat impairments on tributaries. Dams trap the heavy sediments such as sand that are needed downstream to maintain beaches, sand bars and coarse-grained sublittoral habitats. Fine-grained sediments from the erosion of topsoil are suspended in the water and are released by dams. A certain amount of this material is needed by downstream vegetation as a source of minerals and nutrients. Too much can smother the vegetation through siltation and lead to eutrophic conditions. Dams not only trap sediment and water altering both the upstream and downstream habitats, they also isolate populations and block the migration of anadromous fish to upstream spawning grounds. Dams are a major source of impairments on tributaries.

With deforestation the lack of shade, both along the river edge and in the fields that drain into the river, allows the river water to reach warmer temperatures which can be detrimental both to the biota in the river as well as in the downstream wetlands. Expected increases in temperature with climate warming will only heighten this problem. Thus tributaries are affected by activities in adjacent land-based habitats, and effects typically move downstream to the swamp forest, wetland complexes, sand beaches, littoral regions, and finally to the open lake.

Two general impairments are related to the transference of impacts from one habitat to another. First, the shoreline habitats each protect the next inland habitat from storm events. They were each considered impaired due to the impairment of adjacent habitats. Second, modification of the hydrologic regime or water table in one habitat alters the hydrologic regime in all neighboring habitats in a cascading manner. Flowing water forms a geological continuum with a progression of habitat types that develop along the gradient in moisture. Changes in hydrology due to human activities (logging, clearing land, wells, draining, backstopping) have caused impairments in all terrestrial and marginal habitats.

4.4.1.3 Stressors of Aquatic and Terrestrial Habitats

Aquatic Habitats

High Water Levels, Backstopping

The development and maintenance of the nearshore water-based habitats is a dynamic process controlled by along-shore sediment (sand) load in currents, the degree of shoreline indentation and structure, water levels and storms. Historically, the nearshore habitats moved inland or lakeward in response to changes in water levels. One of the major stressors on nearshore habitats (wetlands, sand/cobble beaches, unconsolidated shore bluffs, interdunal wetlands and sand dunes) in the past 30 years has been high water levels, particularly when coupled with shoreline hardening or development. The shoreline habitats have not been free to move inland, but rather are trapped in a narrow area between the water and man-made structures. When shoreline habitats are trapped, they are much more susceptible to the impacts of strong storms that not only severely alter their physical features, but also flush out detrital and planktonic matter into the nearshore margins faster and in higher amounts than what normally occurs from the marshes.

Sand bars and wide stretches of beach and/or submergent vegetation normally dissipate the force of these storms. Dikes were built or improved in the 1970s to protect the remaining marshes along the south shore of the western basin, which otherwise would have been lost (Metzger, Boggy Bottoms, Deer Park Refuges, Mallard, North Bay, West Bay, and Green Creek Clubs, Magee, Navarre, Toussaint, Trenchard's, Rusk, Moxley, and Erie Marshes, Ottawa and Winous Point Shooting Clubs, Little Portage, Toussaint, Little Portage, Pickerel Creek, Willow Point, Pipe Creek, and Pointe Mouillee Wildlife Refuges, Cedar Point and Ottawa National Wildlife Areas).

The vast biodiversity of the wetland wildlife communities are dependent on a vegetated wetland complex. Dikes to protect the remaining wetlands from the combination of high lake levels and backstopping (to protect human use areas from the lake), storm surges, non-native species (i.e. carp, purple loosestrife, and reed-canary grass), have been the only means of survival for these diverse communities.

While isolation of these wetlands from the lake has provided the sole remaining habitat for many wildlife, invertebrates and bird species, it has also impaired their use as fish habitat. Many fish species utilize wetlands at some point in their life. To fully rehabilitate the fish community in Lake Erie, coastal wetlands must be re-connected to the lake. An experiment is underway at the Metzger Marsh where a dike has been engineered to allow limited entry and exit to selected fish entry and close to natural cycles in water elevation, while still protecting the marsh from storms and carp.

High water levels also promote more extensive erosion of bluffs and beaches. In the past, the resulting sand was carried along shore and used to maintain and build up new beaches, underwater sandbars and shoals, and dunes. Breakwaters and other structures built out into the water, as well as the armoring of shorelines with rip-rap and dikes, have altered the intensity and paths of water currents redirecting much of this sediment load to deeper waters. The beaches have become narrower and more vulnerable to storms and seiches. These changes have decreased the feeding, nesting and resting opportunities for shore and wetland birds and wildlife, and increased the likelihood of their disturbance by people and by domestic and wild animals.

Turbidity and Nutrients

Forestry, agriculture, sewage disposal and combined sewer overflows have caused unnaturally high inputs of nutrients and sediments to the lake in the past. Remedial actions have greatly reduced these inputs and their effects on the lake. Eutrophication is no longer considered a widespread issue in the open waters of the lake: phosphorus and chlorophyll *a* levels are close to objectives. Due to periodic anoxia, open waters of the central basin are dominated by tubificid benthos, an indication of impairment. Elevated phosphorus levels, high turbidity, degraded benthic communities (although improved over those in the 1960s), and the abundance of omnivorous fish indicate that tributary mouths are still degraded. Where nutrients have been measured excessive phosphorus remains a localized problem.

Along with nutrients, sediment loading is still a problem in numerous tributaries particularly in the western half of the lake. The offshore waters of the western basin and south shore of the central basin still show residual effects of eutrophication. Benthic communities in these regions are still impaired based on the high densities of tubificid worms, although their densities have been declining through the 1990s. The recolonization of the western offshore regions by *Hexagenia* starting in 1992 is thought to be due to improved oxygen conditions and decreased contaminant concentrations in the sediment throughout much (but not all) of the basin. The increase in the whitefish population indicates that anoxia is no longer a barrier to migration between the western and eastern basins.

Fine sediments have fouled the gravel and coarse substrates in the tributaries, shoreland, and nearshore environments reducing their suitability and use as spawning and feeding areas for fish or habitat for invertebrates. Many river spawning stocks were lost due to a combination of fouled spawning shoals and dams, e.g. northern pike, sauger, muskellunge, whitefish, sturgeon and walleye. Populations in the open lake are now maintained largely by lake spawning stocks. Rehabilitation of streams is allowing the recovery of some walleye river stocks and development of naturalized populations of rainbow trout. Pacific salmon (coho and chinook) are a minor component of stream spawners.

Recent improvements in water clarity during the 1990s can be attributed principally to the high filtering capacity of dreissenid mussels that invaded the lake in the late 1980s. Their impact has been particularly strong in nearshore regions and has allowed the redevelopment of submerged macrophyte beds. Submerged macrophytes in the open lake are not considered impaired. This habitat type is still considered impaired in the tributaries and wetlands due to loss of area (e.g. insufficient area to support wildlife and fish needs), and invasion of non-indigenous (exotic) plant species, but is definitely improving.

Contaminants

Contaminants, which enter the aquatic system through run off from the land, direct disposal and atmospheric deposition, presently degrade areas in the open lake, nearshore and tributaries, particularly in the western basin. Contaminant levels are sufficiently high in some regions of the lake that impacts have been observed in both the highest trophic levels (bald eagles, herring gulls, cormorants, and common tern) and the lower trophic levels (benthic invertebrates). Sediment contamination has been listed as an impairment to benthos in the mouths of the Buffalo, Niagara, Grand, Black, Cuyahoga, Ashtabula, Ottawa, and Maumee rivers and Swan Creek. Degraded benthic communities with higher than normal levels of mouthpart abnormalities (a measure of toxic impact) have been found in the nearshore regions off the Detroit and Maumee rivers. Adult *Hexagenia* collected from western basin nearshore regions had higher contaminant burdens than those offshore further suggesting that nearshore environments have contaminant problems.

Contaminants were considered one of the causes for the loss of *Hexagenia* from the majority of the lake in the mid-1950s. Although the *Hexagenia* population has made a remarkable recovery, particularly in the western basin, starting in the early 1990s its densities remain low through the central section of the basin. Contaminants are hypothesized to be the cause, although dissolved oxygen levels and sediment type are also critical to successful *Hexagenia* reproduction. *Hexagenia* larvae from the region of Middle Sister Island had high burdens of organochlorine compounds and PAHs.

Non-indigenous Invasive Species

Carp were introduced in the last century and are the most physically destructive of the wetland exotics. They root through soft sediments and macrophyte beds while feeding, resuspending sediments and disrupting stabilizing root systems in the process. Their activities magnify the nearshore sediment and turbidity impacts and reintroduce nutrients and contaminants buried in the sediments to the water column.

Eurasian milfoil has invaded submerged macrophyte beds, while *Phragmites*, purple loosestrife, reed-canary grass and hybrid-cattail have invaded the emergent wetland habitats. These invasive species cause impairments because many grow as monocultures that are not suitable for use by native species, reduce habitat complexity and biodiversity, and are less nutritious for the native birds and wildlife. They are also more vulnerable to disease and other pests, as well as disturbance from fire and storms that would result in catastrophic loss of cover for all species.

Perhaps the most obvious and most significant exotic species in Lake Erie are the two dreissenid mussels, the zebra and the quagga mussel. Apart from the effects of their filtering activity on water clarity that was mentioned earlier, their physical presence is altering the nature of hard and soft substrates in Lake Erie.

Terrestrial Habitats

The main causes of impairment in the terrestrial habitats were loss of habitat area, fragmentation, altered hydrology, logging, the invasion of non-indigenous plant species, contaminants, and sedimentation of upland bogs, fens, marshes, and swamps. Logging has impaired the mesic and swamp forests. Removal of the largest (dominant) trees returns the forest to a lower successional state, decreases biodiversity of the entire system, removes food and nest/den sites, and opens up the canopy. Some of the losses of large trees with nesting cavities have been mitigated through nest box programs for such species as flying squirrels, wood ducks, bluebirds, and prothonotary warblers.

More sunlight can enter the forest, which increases the temperature of the leaf litter and dries the forest floor reducing the amount of wet habitat needed by the associated invertebrate fauna and amphibians. Non-indigenous plants have invaded and often form monocultures through the forest. They include garlic mustard, Japanese knotweed, dame's rocket, buckthorn and, in moister areas, *Phragmites*, purple loosestrife and reed-canary grass. The impairments they cause are: insufficient area to support wildlife populations; loss of plant biodiversity in the habitat; loss of habitat complexity; and decreases in nutritional food sources for wildlife.

4.4.2 Fish, Wildlife, Benthos and Plankton Community Impairments

Many species or groups of animals living in the Lake Erie basin were found to be impaired. Impairments were determined on a number of bases: a) population objectives set for key fish, wildlife and benthic species which integrate community function (e.g. mayfly-*Hexagenia*) or represent important functional groups (e.g. diving ducks, top predators etc.), b) ecological function, c) historical records, and d) recent concerns. These translate into impairments in biodiversity, community stability, and food-web structure and function. The causes of these impairments were associated with altered or lost habitat, the invasion of exotic species, human disturbance, and contaminants (Table 4.10).

Contaminant impairment of wildlife was noted for the benthic community, benthic feeding fish (tumors), fish eating birds, mudpuppies in tributaries and possibly for diving birds feeding on dreissenids. Impairments due specifically to contaminants are discussed in Section 4.3. The following sections examine impairments to biodiversity, community stability and food web structure and function, integrating effects across the different trophic levels where possible.

4.4.2.1 Biodiversity and Endangered Species

Biodiversity refers to the number of species supported by a self-sustaining community. Over time, biodiversity normally declines as a community/habitat becomes severely degraded because native species are often depressed or lost. In Lake Erie, biodiversity has been affected by habitat loss and degradation, human disturbance, commercial fishing, the introduction of non-indigenous invasive species and contaminants.

Thirty-four species of fish have been given the status of rare, threatened, endangered, species of concern or extinct in Lake Erie. Some of these were dominant members of the historical fish communities. A large number of the dominant species in the Lake Erie aquatic community are now exotics: smelt, alewife, gizzard shad, round gobies, white perch, rainbow trout, pacific salmonids, dreissenid mussels, *Echinogammarus*, and *Bythotrephes*. As these exotic species became dominant, the biodiversity of the historical fish, benthic, and plankton communities decreased. Smelt are linked to the decline of blue pike, lake herring, the large calanoid, *Limnocalanus*, the marked decrease in *Mysis*, and to the near demise of lake whitefish. The fish species mentioned above had been strongly affected by overfishing and habitat degradation prior to the arrival of the exotic smelt in the lake. Alewife and smelt are implicated in the loss of spoonhead, slimy and deepwater sculpins. Recent evidence suggests that contaminants, in particular 2,3,7,8-tetrachlorodibenzo-p-dioxin, may have been responsible for the final loss of lake trout from Lake Ontario, although the role of thiamine deficiency and the resultant early mortality syndrome (EMS) in larval fish cannot be ruled out. This opens the question of the possible roles of contaminants and diet in the loss of lake trout and other species from other Great Lakes. Dreissenids have eliminated the unionid and sphaeriid clams from all but a few refuges in the wetlands, and are hypothesized to be indirectly responsible for the loss of *Diporeia* from the eastern basin. *Echinogammarus* has replaced *Gammarus fasciatus*, itself an exotic, in many regions.

Wildlife species using with wetlands for breeding habitats or as important migration stopover habitats make up the majority of rare, threatened, endangered, concern, or extinct species within the basin. For one jurisdiction over 80% of the listed birds (43 species), 40% of the listed mammals (two species), and half of the listed reptiles (eight species) use the wetland or terrestrial habitats of the Lake Erie basin. Mammals such as snowshoe hare, rice rat, porcupine, timber wolf, marten, fisher, mountain lion, lynx, elk, and bison have all been extirpated or extremely reduced in range and/or population in the Lake Erie basin. For many of these species, rehabilitation cannot be an option. Habitat diversity is so severely reduced or altered in most wetland and terrestrial habitats, coupled with negative impacts of exotic plants on native vegetation, that diversity of the plant community has changed, which in turn has reduced the potential diversity of the wildlife community.

4.4.2.2 Community Stability

Open Lake

The fish community is considered unstable for a number of reasons: loss of critical habitat, loss of stabilizing effect of top predators, overwintering mortality of nonindigenous species (alewife, shad), competition between native and nonindigenous species, and inefficient transfer of energy through the food web. The loss or degradation of critical spawning/nursery habitat has made reproductive success less predictable and leads to reductions and variability in year class strength of most species. The LaMP has yet to assess reproductive problems in fish. When this assessment is conducted it will address the potential for contaminant impacts on community stability through effects on reproduction. As mentioned in section 4.4.2.1, recent evidence suggests that 2,3,7,8-tetrachlorodibenzo-p-dioxin, may have been responsible for the final loss of lake trout from Lake Ontario. This opens the question of the possible role of contaminants in the loss of species from other Great Lakes and in the present reproductive function. Given that contaminants are: a) causing problems with benthos and top predators, b) at high enough levels to cause fish consumption advisories, and c) associated with tumors in brown bullheads, it would not be surprising if they were affecting the productive capacity of some fish populations.

Native stocks of the historical keystone predators (walleye, sauger, blue pike, northern pike, muskellunge) in cool-water habitats were extirpated or markedly reduced during the period from 1930 to 1972. These species were responsible for maintaining the structure and stability of the fish and lower invertebrate communities. Walleye populations recovered through the 1980s. In recent years, walleye distributions (move to deeper waters) have changed as transparency has increased, reducing the community structuring role of this species. Blue pike would normally occupy this habitat, but have been extirpated from Lake Erie and are now biologically extinct. Northern pike and muskellunge are still rare in many regions, leaving some nearshore areas without strong piscivore structuring. Smallmouth bass provide this function in areas of rock substrate.

Lake trout are maintained by stocking and thus their predatory function is not impaired (their reproduction function, however, is impaired). Fisheries managers are trying to maintain the predatory function in the lake through maintaining native walleye stocks, by stocking lake trout, and by controlling sea lamprey populations. The sea lamprey is an exotic species that, as an adult, is parasitic on larger fish. Sea lamprey control was introduced to allow lake trout to reach sexual maturity, thereby making natural reproduction and self-sustaining populations possible. If the sea lamprey populations are not controlled they can: a) decimate the populations of larger fish, b) prevent lake trout rehabilitation, c) reduce the surplus fish for sport and commercial fisheries, and d) further decrease predator function and energy flow in the lake.

Sea lamprey control provides an excellent example of the potential conflicts involved in managing and trying to restore degraded systems. TFM is applied to tributaries to control the populations of juvenile sea lamprey, but it also kills other species of lamprey, mudpuppies, sculpin, and some invertebrates. Control of sea lamprey is imperative to the health of the fish community. Therefore, alternate strategies of sea lamprey control are presently being investigated by the Great Lakes Fishery Commission to reduce the use of TFM. Between 1990 and 1999, TFM use has been reduced by 39% Great Lakes wide and by 70% in the Lake Erie basin.

The nonindigenous planktivorous fish, alewife and shad, are not well adapted to winter conditions in Lake Erie and often suffer overwintering mortality. The extent of that mortality is dependent on the severity of the winter, which is variable. Native fishes are better adapted to conditions in Lake Erie and are less susceptible to overwintering mortality. Therefore, the population size of native species is less variable and would provide a more stable food source to top predators than that of non-native species. Alewife and shad can outcompete native planktivores, and together with smelt are the dominant planktivores in the lake. With these species as dominants, the stability of the fish community has been decreased. The inefficient transfer of energy through the aquatic food web is discussed in section 4.4.2.3.

The benthic fish community is changing rapidly with the introduction of dreissenids which have altered benthic community structure and productivity, and of gobys which feed effectively on dreissenids and displace native sculpins. This community is not yet stable.

Terrestrial Communities

In terrestrial communities, loss of habitat, contaminants and human interference have resulted in degraded community structure, a loss of predatory function and thus decreased community stability. Fragmentation of habitat and the small size of the remaining habitat impairs wildlife in mesic forest, swamp forest, shrub swamp, mesic prairie, wet meadow and wetland complexes. The loss of habitat has altered community structure and increased the intensity of the interactions (competition, predation) within the remaining habitat. The small habitat areas remaining often can not support animals which require large territories; such as eagles from the beach ridges along the south shore of Lake Erie or bison which once inhabited the mesic prairie. Species also become concentrated in small habitats and are then more easily located and vulnerable to predators and parasites. Fragmentation of habitat is also a serious problem. It particularly affects smaller, less mobile creatures, such as, amphibians, reptiles and insects. When habitats are fragmented, little or no migration occurs between isolated parts of the same habitat type. The resultant small, isolated populations are more susceptible to extirpation. Frogs and salamanders are impaired in interdunal wetlands, wet meadows, shrub swamps, upland marshes and swamp forests partly for this reason. Increased probability of extirpation, predation and parasitism, limited gene pools, and lack of top predators or larger mammals all result in decreased community stability.

The large deer population, loss of bald eagles from the system, small populations of coyote and the extirpation of carnivores such as wolves reflect a loss of top predators in the terrestrial as well as the aquatic community. The impact of range expanding species, such as the cormorant, also suggests a decline in community stability. Several bird populations have expanded greatly and are negatively impacting other species or groups.

- The decline in mainland habitat of colonial water birds is pushing black-crowned night herons and egrets into competition with cormorants, which arrived in the Lake Erie basin earlier this century. The breeding population of cormorants in the Lake Erie basin is restricted to the islands in the western basin. The population is expanding and their guano has the potential to kill the trees in which they nest. The loss of mainland habitat is restricting black-crowned night heron and egret breeding to these same islands and trees. This shrinking habitat base raises long term concerns for the future of these species. Cormorants can nest on the ground, but egret and heron require trees.

- Increasing ring-billed gull populations have displaced common terns from historic nesting sites on beaches, islands, and dune areas and result in increased predation on remaining nesting colonies. This is considered an impairment because the population levels of ring-billed gulls are elevated above historical levels, likely due to the additional sources of food provided by agriculture and human garbage. The piping plover is also impaired from increased ring-billed gull populations and other nest predators such as raccoons and skunks. Human disturbance has been a leading cause of extirpation of breeding piping plovers from the basin.
- Black ducks prefer bog and fen type environments for breeding. Their population is impaired because it is below the objectives set by NAWMP. The recovery of black ducks is hampered by the large populations of mallard which outcompete them in the more open environment created by the altered land uses of the basin. Marsh management creates habitat more favorable for mallard breeding than black duck breeding. Bog and fen habitats cannot be rapidly created or restored for short-term recovery of black ducks.
- Prothonotary warblers, which were considered as representative of the needs of a bird/amphibian complex, are impaired for the most part by habitat changes. However, their existence is jeopardized further by competition with exotic species (European starling, house sparrow) for nest sites and by nest parasitism by cowbirds.

4.4.2.3 Altered Food Web Structure and Function

Aquatic Habitats

Dreissenids have radically changed the food web and in so doing are responsible for impairments to the benthos, plankton and fish communities. The high filtering capacity of dreissenids has probably impaired the phytoplankton community by decreasing phytoplankton biomass and primary productivity in nearshore regions of the eastern basin. This has translated into reduced zooplankton production in those regions and poor recruitment of young-of-the-year fish. Offshore in the eastern basin, dreissenids may be responsible for the decline in diatom species richness and biomass in the spring. An alternate hypothesis is that UVB radiation is responsible. The decline in diatoms is hypothesized to be responsible for the loss of *Diporeia* (benthic impairment), an important food source for fish (whitefish, young lake trout, and smelt) in the hypolimnion.

Dreissenids have also caused the loss of unionid mussels, sphaeriid clams and a shift of the offshore benthic community away from grazing and predacious invertebrates toward oligochaete worms. This new community is less able to support the historic fish community. Loss of *Diporeia* offshore intensified the predation of smelt on mysids and zooplankton. Strong predation on zooplankton by alewife and smelt has resulted in zooplankton communities composed of small species and in lower total zooplankton production.

The addition of *Bythotrephes*, a predatory zooplankter, has inserted another trophic level between herbivorous cladocerans and fish. *Cercopagis*, another predatory zooplankter, is expected to arrive soon. This also decreases the efficiency of energy flow up the food web. The abundance of *Bythotrephes* in this planktivore dominated system further suggests that *Bythotrephes* may be an energy sink. The zooplankton community in the eastern basin is not transferring energy to fish as efficiently as it might. Thus, in total, the food resources of fish in the eastern basin have been reduced. This food web disruption of the pelagia of the eastern basin is an impairment of the fish community as fish community goals and objectives for harvestable surplus fish cannot be met.

In addition to altering the food-base of the pelagic fish community in the eastern basin, dreissenid impacts on water clarity have affected the efficient use of this food by the fish community. The increased transparency of the water column has displaced the principal predator, walleye, from much of the habitat. The smelt population in the eastern basin is in poor condition. There is no longer efficient transfer of energy to a top predator. Thus, the surface waters of the eastern basin are impaired due to lack of a strong predator species, which can utilize the habitat vacated by walleye. The food-web disruption of the pelagia due to dreissenids has been moving into the central basin. In the eastern and central basins, the decrease in smelt and rapid increase in gobies, which feed on dreissenids, is expected to affect predator feeding patterns and availability of predators to the fishery.

In the western basin, *Microcystis* blooms have developed in association with dreissenids. The cause of these blooms is being investigated and is hypothesized to be due to nutrient release by dreissenids. *Microcystis* is a blue green alga, which can produce toxins and is not readily consumed by other organisms. After many years of being absent, blooms have appeared sporadically for a number of recent years over a wide area, and are therefore likely a signal of impairment.

Dreissenid impacts have also benefited some groups of plants and animals. Increased water clarity has allowed the expansion of submerged macrophyte beds, and therefore the expansion of northern pike, muskellunge and sturgeon populations associated with this habitat. These species are still rare in Lake Erie. The increased macrophyte beds should help protect the emergent marshlands and provide new habitat for macroinvertebrates. Lake Erie is a critical staging area for diving ducks, such as mergansers, redheads, canvasbacks, and greater and lesser scaup, which use this habitat. Vegetation eaters, such as redhead and canvasback ducks, are showing wider use of sites. Mollusc eaters, such as scaup, are remaining for extended periods to feed on dreissenids. Mergansers are able to more efficiently feed on their small fish prey in the clearer water. Diving ducks, except for scaup, are meeting North American Waterfowl Management Plan (NAWMP) objectives and are not impaired.

Terrestrial Habitats

In the terrestrial communities, the invasion of exotic plants and harvesting of mast-bearing trees has altered the base of the food webs. Exotic plants, such as garlic mustard, Japanese knotweed, dame's rocket, buckthorn and, in moister areas, *Phragmites*, purple loosestrife and reed-canary grass, often form monocultures thereby reducing the variety of foods and are often less nutritious than the native plants.

Direct human disturbance has also reached the point of impairing wildlife populations thereby affecting community and food web functions. Through recreational use of habitats, people and their pets have negatively impacted these sentinel groups/species: diving ducks, the common tern, piping plover, and other shorebirds, bald eagles, black terns, snapping turtles and eastern spiny softshell turtle. In some instances, animals are scared from roosting or feeding areas, which incurs an energetic cost. In other instances, the reproduction of the organism is affected, which incurs a population cost. Human disturbance was noted as a factor affecting wildlife in a number of different habitat types: open water, islands, beaches, bluff, interdunal wetlands, mesic prairie, mesic forests and swamp forests. Only in submerged and floating macrophyte beds, beaches, and sand dunes was human recreational activity impairing the habitat, per se.

4.4.4 Research Issues/Data Gaps

Plankton

- Understanding the cycling of phosphorus and nitrogen in the presence of dreissenid mussels: impacts on phytoplankton composition, primary production and the *Microcystis* occurrence.
- Microcystis problem: conditions that promote *Microcystis*, what are the actual quantities, is it producing toxins and when.
- Need to know the partitioning of primary production between the benthic (periphyton) and pelagic phytoplankton: how it changes with depth, substrate and increased light penetration
- What is the role of UV radiation: has it decreased or altered the distribution of primary production through the season, what is the relative importance of UV radiation versus dreissenid filtering in the decline in diatoms in the spring.
- How important is the decrease in food supply (diatoms and zooplankton) after the arrival of dreissenids to the growth rate and survival of the mysid population in the eastern

basin: conversely how important is planktivory now in suppressing the mysid population.
- How important is *Bythotrephes* in depressing energy flow from zooplankton to fish: temporally? Spatially?
- How will *Cercopagis*, a new predatory zooplankton, affect zooplankton community structure and energy flow.
- What is the optimum mean individual size range (0.7-0.9 mm?) of the zooplankton community for effective energy flow up the food chain. – develop as a management tool
- Need for information on zooplankton and phytoplankton biomass and community structure in shallow littoral and nearshore habitats. VERY little information available.

Benthos

- Data is needed for benthic community composition in Canadian wetlands, shorelands in both Canada and the U.S., central basin nearshore, especially Canadian waters, and central basin profundal zone.
- An improved understanding is needed of benthic-pelagic processes and benthic biotic/ physical feedback loops, especially in the western basin.
- A GIS facilitated, integrated data-base of all historical and current benthic data is needed.

Fish

- Data on lakewide phosphorus loadings needs to be collected and reported annually in a manner that allows long-term trends to be discerned.
- A number of Lake Erie fish habitat mapping initiatives are either underway or proposed. These projects will provide inventory data regarding fish habitat quantity, supply, and changes over time. In addition, Ohio Department of Natural Resources (ODNR) has been exploring the relationship between Lake Erie environmental conditions, including habitat, and known fish reproductive centers or *hotspots*. A conceptual framework is under development and will be used to identify the specific driving environmental forces that produce these observed, repeatable patterns in fish community composition and reproduction. It is hypothesized that the driving forces are linked to tributary conditions versus open lake conditions. If this is the case, fish management actions will become more watershed based versus open-lake focused. The LaMP offers an important opportunity to link the results of both projects into a more comprehensive picture of Lake Erie fish habitat needs.
- Genetic diversity in fish is measured by determining whether discreet stocks (i.e. river spawning versus reef spawning) exist within a particular species and population. Research has begun to identify genetic markers for Lake Erie larval fish. If a relatively inexpensive genetic marking technique can be developed, monitoring of fish stocks can be more detailed. The overall result will be better information on the diversity and health of particular Lake Erie fish species.
- Further research into alternative methods of sea lamprey control that maximize effectiveness of the control efforts while minimizing their economic and environmental costs.

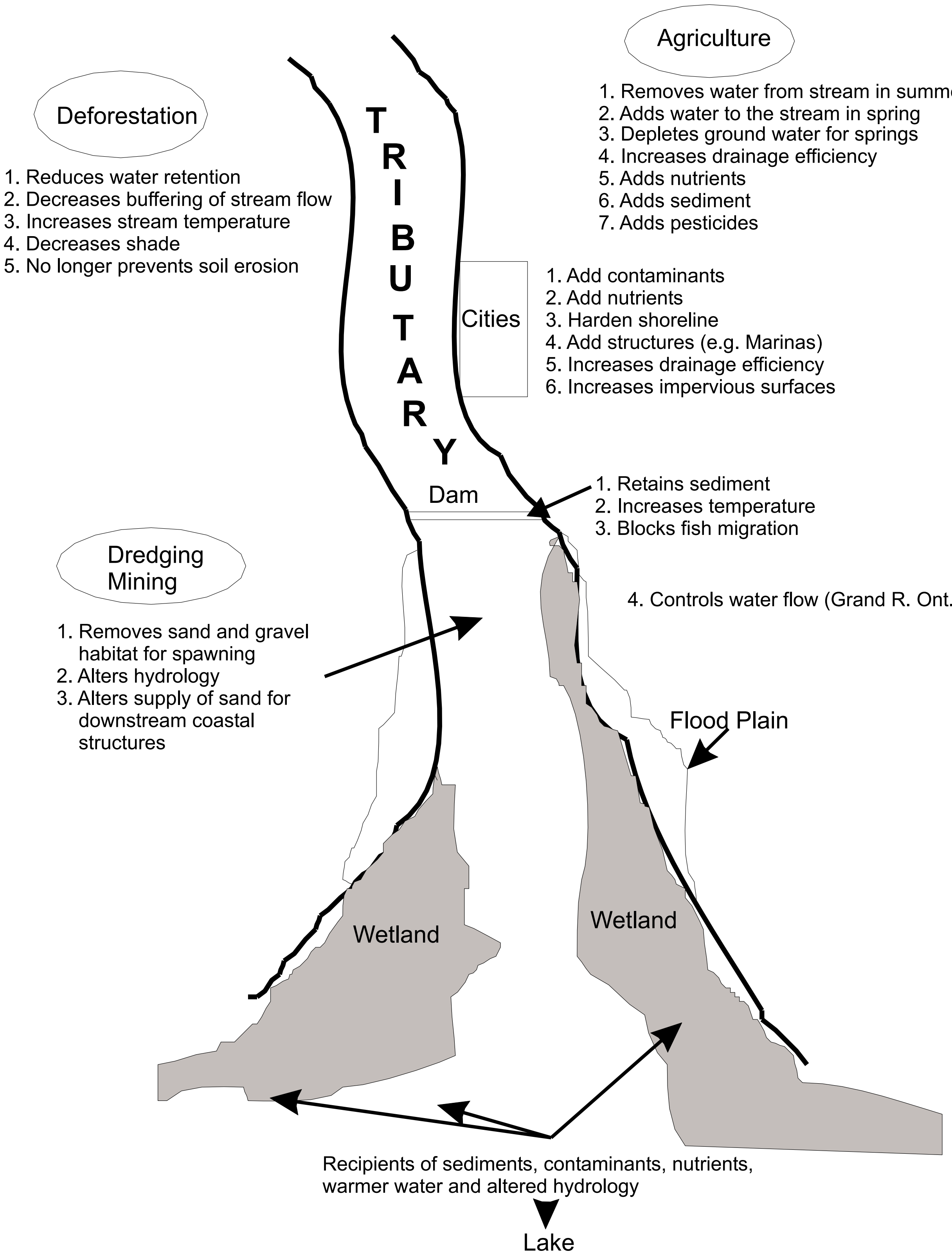
Wildlife

- Given the conflict between the need for dikes to manage wildlife that use Lake Erie wetlands and the negative impacts of dikes on fish, data is needed on the critical time periods when fish need passage into and out of wetlands and technologies that allow this to happen.
- The known conditions of Lake Erie basin populations of amphibians, reptiles, birds, mammals and Lake Erie wildlife habitats were assessed for the Lake Erie LaMP. The common theme from those experts who provided data was that surveys of population distribution, status, and trends are needed for many Lake Erie wildlife species. In particular, amphibian, reptile, and mammal data is sparse, particularly for nongame species without existing management objectives.
- Ducks and geese - In general, migration and breeding surveys are needed to assess population size, reproductive success, turnover rates during migration, reasons for local population shifts, impacts of human disturbance, and diet. More specific data is needed

regarding particular species, including black duck, canvasback, mergansers, goldeneye, wood duck, greater and lesser scaup, southern James Bay Canada goose. For dabbling ducks as a group, an assessment is needed of factors, other than habitat, limiting populations habitat.

- Passerines (songbirds)-banding is needed to monitor migratory populations and consistent ongoing, long-term censuses are needed. A regional data-base to house data collected is also needed.
- Piping Plover - causes of population decline in Lake Erie basin. Habitat degradation and human disturbance are factors. However, the absence of plovers from Long Point Bay where habitat and disturbance are not problems, indicates that another stressor may be affecting the population.
- Shorebirds - an assessment is needed of factors, other than habitat, limiting populations. For certain species, such as buff-breasted and upland sandpipers, data needs include: number migrating through Lake Erie basin, length of stay, population trends, preferred breeding and migration habitat, and best management practices.
- Herons and egrets - need more detailed data on effects of competition with cormorants.
- Bald eagle - need to clarify relationship between depressed reproduction and contaminants, data on contaminant loads in adults, and role of environmental conditions in effects of contaminants.
- Marsh birds - information is needed on the effect of *Phragmites* on this group. Need to know habitat requirements and threats during migration. Need better survey methods to collect data on population trends.
- River otter/mink - need information regarding changes in distribution within Lake Erie basin. Need more details on predator-prey relationship between mink and muskrat, and its resulting impact on habitat.
- Continued identification, surveys, and preservation/restoration of exemplary habitat with high values for wildlife function is needed.

Figure 4.1 Summary of impacts on tributaries from adjacent habitats and the impact of tributaries on downstream habitats



4.5 References

Culver, David A. 1999. *Toxicity, Ecological Impact, Monitoring, Causes and Public Awareness of Microcystis Blooms in Lake Erie*. Report to the Lake Erie Commission.

Gilderhus, P.A. and B.G.H Johnson. 1980. Effects of Sea Lamprey (Petromyzon marinus) Control in the Great Lakes on Aquatic Plants, Invertebrates, and Amphibians. *Can. J. Fish. Aquat. Sci*. 37:1895-1905.

IJC (International Joint Commission). 1989. Proposed Listing/Delisting Criteria for Great Lakes Areas of Concern. *Focus on International Joint Commission Activities* Vol.14(1): insert.

Matson, T.O. 1990. Estimation of Numbers for a Riverine *Necturus* Population Before and After TFM Lampricide Exposure. *Kirtlandia* 45:33-38.

National Research Council of Canada. 1985. TFM and Bayer 73 – Lampricides in the Aquatic Environment. NRC Associate Committee on Scientific Criteria for Environmental Quality. *NRCC Publication No. 22488* pp. 184.

Ohio Sea Grant. 1999. Research review, Zebra Mussels: Key to Contaminant Cycling. *Twine Line* Vol 21/No. 4.

Rouse, J.D., C.A. Bishop, and J. Struger. 1999. Nitrogen Pollution: An assessment of the impact on amphibians. *Env. Health Persp*. 107:1-6.

Straughan, Cameron A., Matthew Child, and Derek Coronado. 1999. *Detroit River Update Report (Final Draft)*.

United States Environmental Protection Agency. 1999. Mercury Meeting, Binational Meeting, Detroit, Michigan, USA. Cited in Straughan *et al.*, 1999.

Weisser, J.W., Gon fish, aquatic insects, and an amphibian in the Grand River in Lake County, Ohio, 1987. *Great Lakes Fishery Commission Project Completion Report*. Great Lakes Fishery Commission, Ann Arbor, MI.